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REPORT ON

IMMEDIATE PUBLIC WATER SUPPLY NEEDS
OF THE
CITY OF NEW YORK
AND
COUNTY OF WESTCHESTER

August 1966

STATE OF NEW YORK

DEPARTMENT OF HEALTH

CPWS - 27

Metcalf & Eddy • Hazen and Sawyer • Malcolm Pirnie Engineers

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New York

METCALF & EDDY—HAZEN AND SAWYER—MALCOLM PIRNIE ENGINEERS

A JOINT VENTURE

60 EAST 42ND STREET
NEW YORK, NEW YORK 10017
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August 19, 1966

Board of Water Supply
City of New York
120 Wall Street
New York, New York
Attention: Mr. Edward C. Maguire, President

Department of Public Works
County of Westchester
County Office Building
White Plains, New York
Attention: Mr. James C. Harding, Commissioner

New York State Department of Health
84 Holland Avenue
Albany, New York
Attention: Hollis S. Ingraham, M.D., Commissioner

Gentlemen:

As the first step in a comprehensive intermunicipal public water supply study for the City of New York and Westchester County, we have investigated the immediate public water supply needs. As required in our Contract CPWS-27, effective May 18, 1966, we now submit the following report on this phase of the over-all study. The report includes (1) an outline of a management plan to serve immediate needs and (2) a discussion of measures to be taken to serve immediate needs.

A second report covering other phases of the comprehensive study will be submitted at the conclusion of the study.

Respectfully submitted,

METCALF & EDDY
HAZEN AND SAWYER
MALCOLM PIRNIE ENGINEERS
A Joint Venture

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Robert D. Mitchell

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WATER SUPPLY REQUIRED

Population

For the purposes of this report, we have estimated that by 1975 the population of New York City will reach 8,000,000 and that of Westchester County, 980,000, making a total population to be served of 8,980,000. The forecast for New York City corresponds to those made by numerous agencies. Although these forecasts are tentative, they are sufficiently accurate for estimating immediate water needs.

Past Water Consumption

Water supplied to New York City and Westchester County has averaged approximately 1,300 mgd. (million gallons per day) over the past six years as indicated in Table 1.

Table 1. Summary of Daily Average Rates of Water Supply, 1960-1965

	Daily average rate, mgd.				
	Supply to NYC		Supply to Westchester County		
Year	From municipal sources	From investor-owned utilities	From NYC sources	From local sources	Total
1960	1,147	52.1	57.2	33.6	1,290
1961	1,167	53.8	64.0	31.8	1,317
1962	1,151	56.6	66.5	31.9	1,306
1963	1,159	58.6	75.9	26.2	1,320
1964	1,131	58.2	78.7	28.3	1,296
1965	994	58.1	68.3	27.7	1,148

The quantity of water supplied annually in New York City by the city system and investor-owned companies from 1946 through 1965 is shown on Fig. 1. Quantities supplied in Westchester County from local sources during the years 1960 through 1964 are tabulated in Appendix Tables A-1 and A-2 and are summarized in Table 1.

Fig. 2 shows the monthly average rates of supply to the city for 1960 through 1965.

In Westchester County, substantially all consumption is metered. In New York City, metering is virtually limited to industrial and commercial services. Nonmetered use includes residential consumption (except for that by some 20,000 metered residences out of a total of 690,000 residences and apartment buildings served), municipal use, and leakage. Nonmetered water use in New York City averaged 116 gcd. (gallons per capita per day) for the years 1954 through 1964 as shown in Table 2.

From the American Water Works Association publication, "A Survey of Operating Data for Water Works in 1960," we have obtained per capita totals of nonindustrial and noncommercial use plus unaccounted-for water* from 24 water utilities in the United States serving populations of over 500,000 persons. In Appendix Table A-3, we have compared the average per capita nonmetered water in New York City with the above-mentioned data. For 12 of the utilities the figure was

* Unaccounted-for water, as commonly reported, includes leakage from the system, water used for fighting fires and flushing the system, and under-registration of customers' meters.

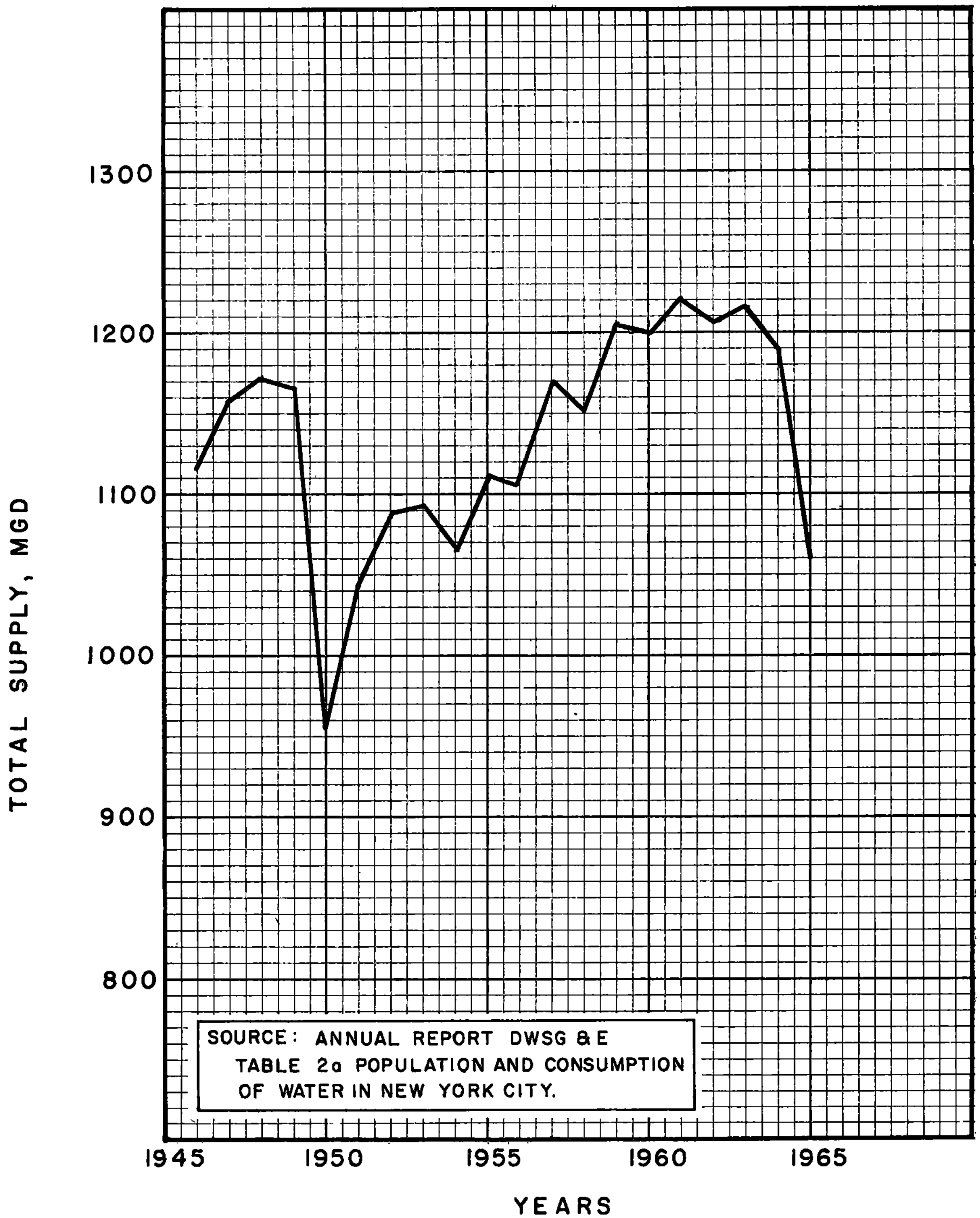

FIG. 1 ANNUAL AVERAGE RATE OF TOTAL SUPPLY TO NEW YORK CITY
(INCLUDES SUPPLY BY INVESTOR-OWNED WATER UTILITIES)

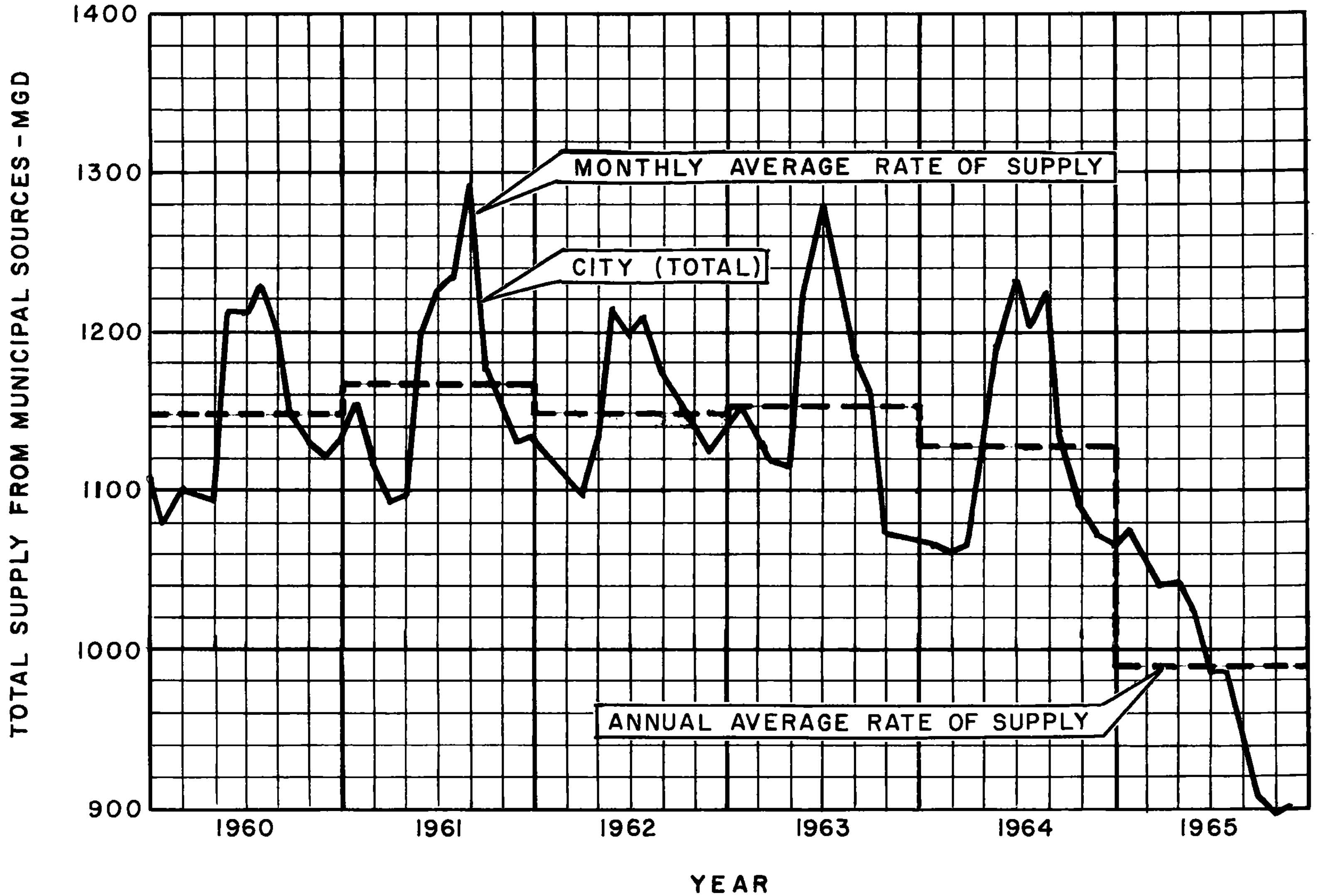

FIG. 2 MONTHLY AVERAGE RATE OF TOTAL SUPPLY TO NEW YORK CITY

(SUPPLY FROM INVESTOR-OWNED UTILITIES NOT INCLUDED) less than 80 gcd. and for 14 it was less than 100 gcd. New York City stood nineteenth in order of increasing magnitude, with an average of 116 gcd.

Table 2. Per Capita Nonmetered Water Use in New York City*

	Gallons per capita per day				
Year	Manhattan and Bronx	Brooklyn	Queens	Richmond	The City
1954	131	80	81	74	103
1955	134	98	83	83	111
1956	126	106	81	80	110
1957	136	111	81	95	118
1958	131	111	91	82	116
1959	138	116	104	87	122
1960	134	114	108	70	120
1961	139	106	119	93	122
1962	123	111	140	79	120
1963	126	114	117	89	120
1964	125	107	120	90	116
Average	131	107	101	84	116

*Supply from municipal sources only; 650,000 population deducted from Queens and the city to allow for supply from investor-owned utilities.

The effect of water conservation measures on total water consumption in the city is shown clearly on Fig. 3. From this figure, it may be seen that the annual average daily draft dropped from 150 gcd. in 1948 to 121 gcd. in 1950, a reduction of some 19 percent during a period of water use restrictions.

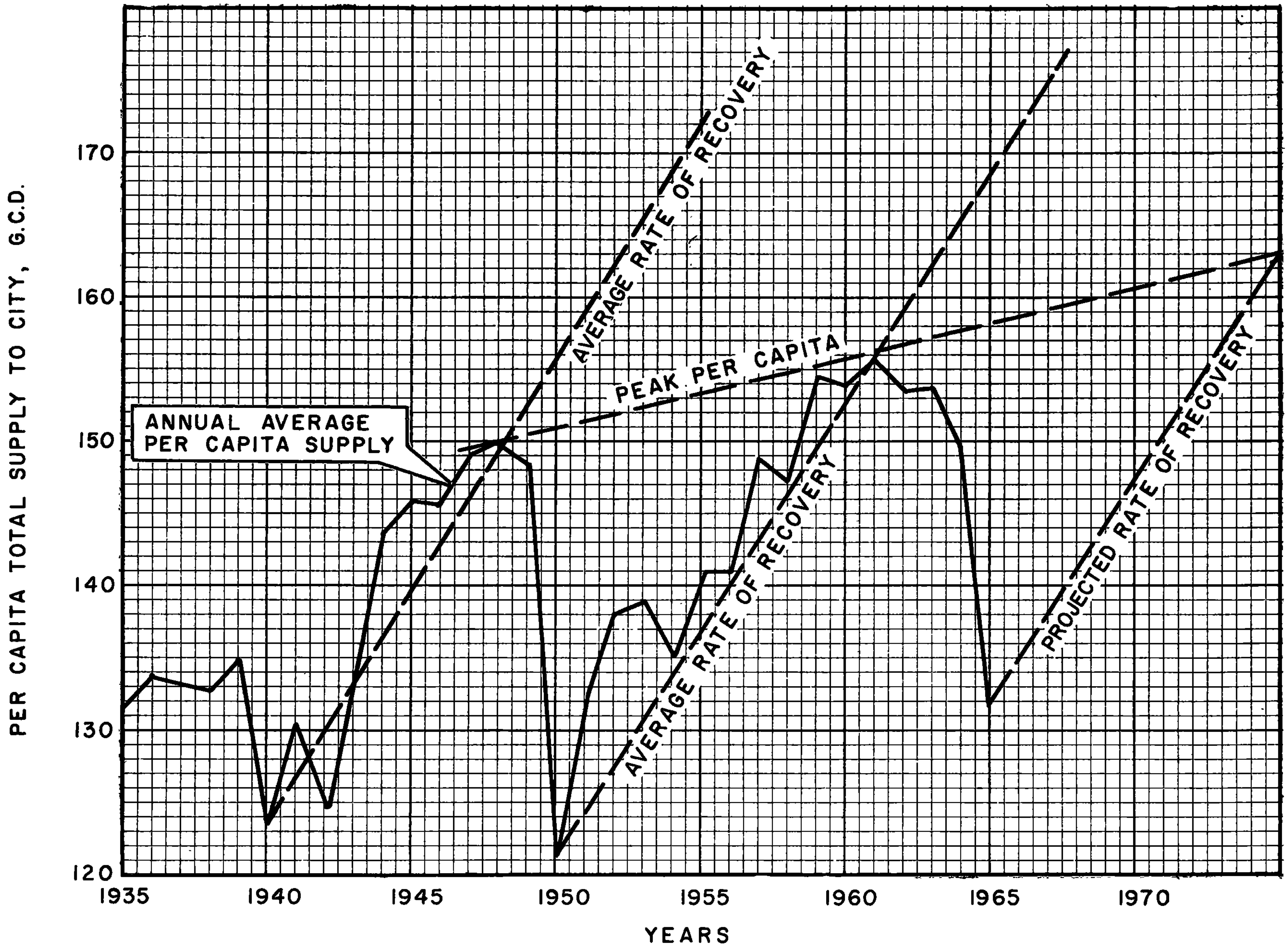

FIG. 3 PER CAPITA TOTAL SUPPLY TO NEW YORK CITY
(INCLUDES SUPPLY FROM INVESTOR-OWNED UTILITIES)

Following the removal of restrictions, the total draft increased until in 1961 it reached a maximum of 156 gcd. The over-all increase in the period from 1948 to 1961 was equivalent to 6 gcd., or about 0.46 gcd. per year. This may be compared to an increase in consumption of 0.5 to 2.0 gcd. per year commonly allowed in planning water facilities throughout the United States.

Again referring to Fig. 3, the annual average daily draft dropped from 156 gcd. in 1961 to 132 gcd. in 1965, a reduction of about 15 percent during this period of restricted water use.

Although the conservation campaign of 1963-66 was more intensive than the 1949-50 campaign, the reduction in per capita water consumption was somewhat smaller in spite of excellent cooperation on the part of the public.

Water Supply Required in 1975

The future water supply requirements of New York City will depend partly on whether additional effort is made to reduce nonmetered use and leakage or whether present practices continue. It is obvious, however, that universal metering would take several years to complete and for its impact to be ascertained. Likewise, the benefits from additional leak-detection efforts would be produced over a period of years.

Projecting the average increase in the total draft between 1948 and 1961 into the future indicates a requirement of about 163 gcd. by 1975. If the average rates of per capita increase experienced between 1940 and 1948 and again between

1950 and 1961 are applied to the 1965 rate (see Fig. 3), a total supply of 163 gcd. is also indicated as being required in 1975. Therefore, if present practices are continued in the future, a supply equal to 163 gcd. in 1975 should be provided.

On the other hand, if universal metering* is accomplished and if leak detection and elimination are carried out in an efficient and energetic manner, a substantial reduction in consumption is believed to be possible. For the purpose of estimating a range of consumption in 1975, we have assumed a reduction in noncommercial use plus unaccounted-for water to 100 gcd. and in the total consumption, including commercial and industrial use and supply from investor-owned utilities, to 136 gcd. One-half to two-thirds of such reduction in consumption might result from universal metering and the remainder from improved leakage control.

Estimate Based on Continuation of Present Practices. To provide 8,000,000 people with 163 gcd. in 1975 would require an annual average supply for New York City of 1,304 mgd., of which some 58 mgd. would be from investor-owned sources. By 1975 approximately 100 mgd. would be needed in Westchester from New York City sources, in addition to the 28 mgd. available in the county. The supplies in Westchester County have been developed to their practicable limit and cannot be counted on for any significant increase in yield.

*"Universal metering", as used in this report, means the metering of all services, but not the metering of supply lines to individual apartments in multifamily buildings.

The total supply required in 1975 is summarized as follows:

	Mgd.
Supply to New York City	
From municipal sources	1,246
From investor-owned sources	58
Supply to Westchester County	
From New York City sources	100
From local sources	28
Total	1,432

Estimate Based on Reduction in Nonmetered Use and Leakage. We have previously indicated that, with universal metering and more effective leakage control, it may be possible to reduce nonindustrial and noncommercial use plus unaccounted-for water to 100 gcd. by 1975. At the same time commercial and industrial water consumption is likely to grow each year as shown on Fig. 4. If the over-all rate of increase experienced between 1954 and 1964 continues, the metered industrial and commercial water sales may be expected to increase from 281 mgd. in 1964 to 300 mgd. by 1975. Assuming Westchester County demands and the investor-owned supplies continue as above, the total supply thus required in 1975 would be as follows:

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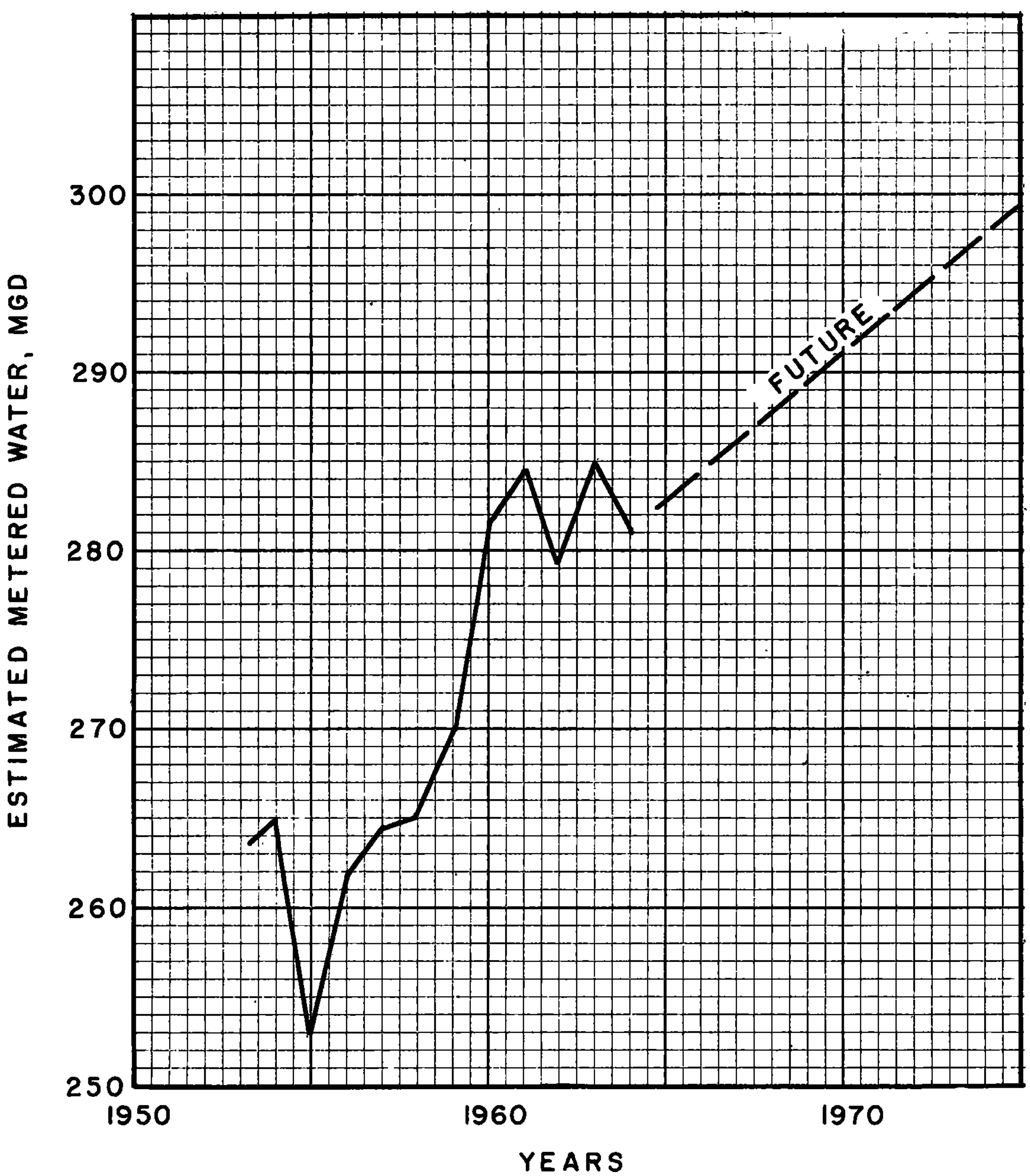

FIG. 4 ESTIMATED METERED WATER SOLD IN NEW YORK CITY

	Mgd.
Supply to New York City	
From municipal sources	
Nonindustrial and noncommercial uses plus unaccounted-for water	730
Metered use	300
From investor-owned sources	58
Supply to Westchester County	
From New York City sources	100
From local sources	28
Total	1,216

Yield of Present Sources and Relation to Water Demands

The prolonged drought in recent years has demonstrated clearly that earlier estimates of the safe yield of the New York City system must be revised downward. In spite of severe restrictions on water use, and supplementary supplies from Long Island and the Hudson River at Chelsea, water demands have been met only by reducing Delaware River releases below the quantities stipulated by the U. S. Supreme Court. Had the Delaware River Basin Commission not acceded to the city's urgent request and relaxed the release requirements, the water shortage in New York and Westchester would have been much more serious, if not intolerable.

Accurate forecasts of safe yield are impossible as long as the drought continues, and reliable figures may not be available for some time. A comprehensive analysis of the safe yield is underway, however, and the best possible estimates will be included in the final report. It is clear now that if the drought should continue, or recur within a few years, there would not be enough water to meet normal demands in New York City and Westchester. Water metering and an intensified leak-detection and stoppage program would help considerably, and would reduce the need for restrictions on water use. Even with these steps, however, continued relaxation of the Delaware River release formula almost certainly would be necessary.

The estimates of water demands in 1975 and the safe yield of the present works are reliable enough to indicate clearly that a major addition to the supply system will be needed if normal water service is to be maintained during severe droughts. The situation is critical and demands prompt action, for the planning, design, and construction of large-scale water projects is likely to take 10 years, and perhaps considerably longer if interstate water rights are involved.

In the pages following, we outline, first, measures that would close the gap between supply and demand by reducing water consumption in New York City and, second, steps that could be taken to increase the quantity of water available during droughts.

MANAGEMENT PLAN TO SERVE IMMEDIATE NEEDS

Under ordinary conditions, the two most effective means of water conservation are, first, leak detection and stoppage and, second, universal metering, with proper rates and maintenance. In emergency, or during extreme droughts, restrictions on water use may also be necessary.

We have indicated that, with universal metering and more effective leak detection and elimination, nonindustrial and noncommercial use plus unaccounted-for water supplied from municipal sources may be reduced to 100 gcd. by 1975. To accomplish this goal, we recommend that:

1. An intensified leak-detection and stoppage program be instituted immediately and prosecuted energetically on a continuing basis.
2. Universal metering be instituted immediately and be programmed for completion before 1975.
3. The procedures for metering, reading, and billing be modernized and that computer facilities be used to the fullest extent feasible.
4. Pending completion of universal metering, premises served by unmetered water services be inspected for leakage and violations of Department of Water Supply, Gas & Electricity regulations at least once every five years.

5. Water rates be revised so that a metered supply becomes more attractive financially than an unmetered supply to a majority of customers.

Until such time as the leak stoppage and metering program reduces the wastage of water, water use restrictions will be necessary in the event of droughts. Thereafter, restrictions should be applied sparingly and only when the need for additional water conservation is demonstrated. Exceptions to this would be the prohibition of the use of city water for cooling where the cooling water is not recirculated and any unmetered use where substantial quantities of city water are used and other less wasteful practices could be substituted reasonably.

Leak Detection

In the early 1900's, New York City was one of the pioneers in leak-detection efforts, and for many years effective leak-survey crews were maintained. With increasing labor costs and other difficulties, much of the leak-detection work has been suspended. Presently, in the five boroughs, only Manhattan and the Bronx have a water waste department functioning. In the other three boroughs, obvious leaks are located and repaired by staff of the regular maintenance shops.

Formerly there were four work groups in the Manhattan Water Waste Department. Two groups would work on leak surveys on a systematic street-by-street basis, and the other two groups would work on leak complaints originating from one of the Manhattan Department of Water Supply, Gas & Electricity repair shops. In July 1965, the two-section setup was discontinued because of a gradual loss of manpower through attrition. Vacancies were not filled.

Records of the Department of Water Supply, Gas & Electricity show that there has been a gradual but pronounced shift in the number of leaks located as a result of systematic surveys in comparison with those mentioned in complaints. Prior to 1961, two to three times as many leaks were located by survey as from complaints; in 1965 the reverse was true. It is evident from these records that the city recently has not been aggressively seeking sources of leaks, but has been waiting until the effects of the leakage have become evident and have given rise to a complaint.

In 1965 New York City engaged Pitometer Associates, Incorporated, of New York City, to make a water waste survey of the city distribution system. The survey has been completed and a report submitted, but to date a copy of the report has not been made available to us. We have, however, been given some of the highlights.

Pitometer measured the total water supplied to Brooklyn and Queens and to three service areas in Richmond, 10 districts in Manhattan, and 13 districts in the Bronx. The individual districts in Manhattan and the Bronx were quite large and in some cases were up to 10 times the area with which Pitometer normally works.

Detailed leak detection in the field was done to a considerable extent with sensitive listening devices. Such survey, however, was limited to only four districts in Manhattan and three districts in the Bronx. About 570 out of 5,980 miles of main in the city were surveyed.

Pitometer Associates computed from its leakage survey an average loss of 5,820 gpd. (gallons per day) per mile of main, or 34.8 mgd. for the entire city. From an analysis of day and night water consumption, they estimated a total leakage of 16.8 mgd. The average of the two figures is approximately 26 mgd. During 1965, Department of Water Supply, Gas & Electricity forces discovered and stopped 29.6 mgd. in leaks in addition to those detected by Pitometer Associates, so that the total leakage found in 1965 exceeded 55 mgd. For a population of 7,300,000 served from municipal sources, such leakage represents an average of 7.5 gcd.

The leakage survey conducted by Pitometer was much more limited than that company feels is desirable for effective leak detection. Furthermore, the city's leak-detection efforts have been severely limited. We consider it highly desirable for the city to engage in a continuing leak-detection program, either under the full-time direction of an experienced firm of professionals or with an equivalent staff under the Department of Water Supply, Gas & Electricity. In either case, the program should be geared to assuring that 20 percent of the city will be covered annually so that the entire city will be surveyed every five years. Under such a program, the annual reduction in leakage might average 10 gcd., or 73 mgd., for three to five years at least. Thereafter, the gains would be less.

Metering

Universal metering in New York City has been recommended by nearly every expert, committee or commission which has studied the matter over the past 50 years. We endorse this recommendation, even though we recognize the practical difficulties in such a program and realize that the full impact of the program will not be felt for several years. Even a crash program of metering would take at least five years, and completion in 10 years is much more likely. By starting the program promptly, however, some benefits will be obtained in the immediate future and progressive metering should keep the nonindustrial and noncommercial per capita use at or below present levels.

The city took an initial step toward universal metering by adjusting water rates last July so that metered rates are slightly lower than unmetered charges. We are informed that there was an immediate increase in requests for new meter installations as a result of this revision. This device should be exploited to the fullest extent practicable.

For universal metering to be fully effective, there should be improvements in the procedures for reading meters, computing billings, and the maintenance of meters. We believe that billing procedures should be computerized to the fullest extent feasible. All new meter installations should be of the remote reading type wherever there will be any question of

access for reading. Maintenance procedures should be revised so that all meters will be checked at regular intervals, and replacement meters should be installed when meters are removed for repairs.

With billing being done by computers, it should be practical to divide the city into meter districts compatible with leak-detection measuring facilities. By computer methods, the consumption in such districts could then be compared readily with measured supply, and major leakage thereby be more readily detected. The computer would also facilitate comparisons between metered and unmetered use, thus providing a check on unaccounted-for water.

Water Use Restrictions

Experience with the 1949-1950 and the 1962-1965 droughts has indicated that water utility customers will cooperate by restricting their use of water when a genuine shortage of water supply exists. Nevertheless, customers cannot be expected to exercise patience indefinitely throughout a succession of emergencies.

The Department of Water Supply, Gas & Electricity made an all-out effort during the present drought to make water restrictions as effective as feasible. The Division of Water Conservation is currently assessing the effectiveness of the various types of restrictions imposed, but the results of this study are not yet available.

Effective programs of leak detection and universal metering, together with thorough inspection of unmetered premises during the transition period, may eliminate the need for overall water use restrictions for at least several years. Limited summertime restrictions, however, may be necessary in outlying areas where lawn sprinkling demands exceed distribution system capacity. In any event, restrictions should be applied only when necessary, and at such times should be enforced impartially and rigorously.

The Department of Water Supply, Gas & Electricity maintains daily records of water supplied and water in storage. These data should be adequate for short-range forecasting of a possible deficiency in supply. An emergency should be considered as possible whenever the water in storage, augmented by estimated runoff over the following 12 months equal to that experienced in the driest year of record, is inadequate to meet the projected consumption. Public notice should be issued promptly of the pending possible emergency, and a plan of operation should be set up. Weekly reports in the newspapers of the water supply available and current rates of use will keep the public informed. Under genuine emergency conditions, such information is essential if public cooperation is to be generated.

IMMEDIATE MEASURES TO INCREASE WATER SUPPLY

Possibilities Considered

We have considered a number of possible ways in which the water supply might be increased. This investigation was undertaken in the hope of uncovering some measures that could be accomplished quickly and would provide additional water at fairly low cost. We have considered only measures that could be implemented in a relatively few years, say five to eight years. The investigations have been necessarily brief and preliminary in nature and aimed only at developing approximate potential yields and order of magnitude cost estimates. The time available was far too short for developing details or exploring possible objections.

The measures considered consist of the following:

1. Hudson River Pumping Plant addition
2. Westchester County local development
3. Expansion of Croton system
4. Floodwater skimming - Westchester, Putnam, and Dutchess Counties
5. Candlewood Lake project
6. Catskill flood skimming
7. Delaware flood skimming
8. Cannonsville flashboards
9. Long Island ground water
10. Cloud seeding
11. Sea water conversion.

Fig. 5 shows the locations of specific projects.

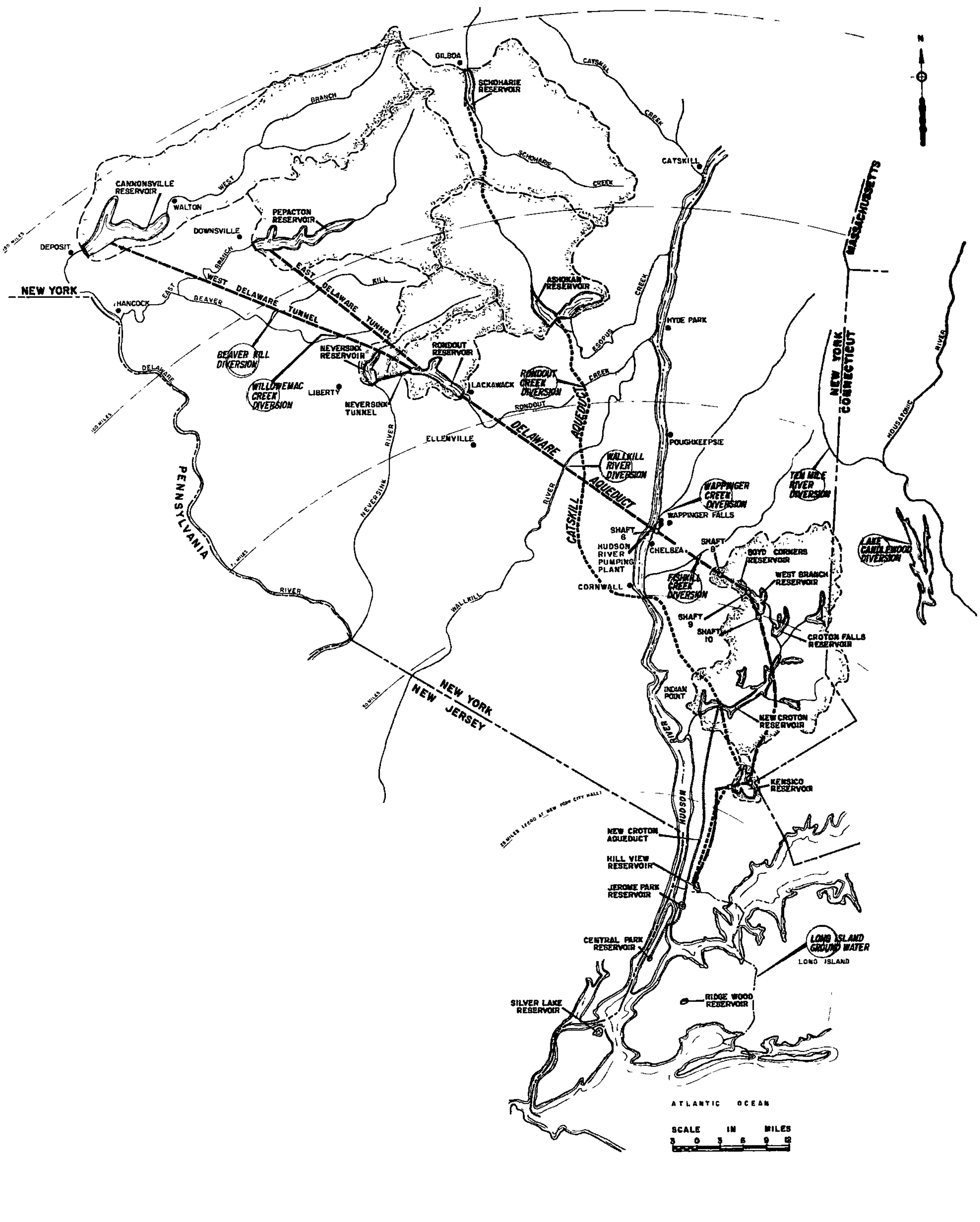

FIG. 5 POTENTIAL IMMEDIATE SUPPLEMENTARY WATER SUPPLY PROJECTS

Use of water from the proposed pumped storage hydroelectric project of the Consolidated Edison Company at Cornwall was considered in a report made by Metcalf & Eddy to the Board of Water Supply in April of this year, in which it was recommended that the city not adopt this plan.

Hudson River Pumping Plant Addition

In 1964, New York City obtained a permit from the New York Water Resources Commission to rebuild the Chelsea Pumping Station and to pump 100 mgd. from the Hudson River into the Delaware Aqueduct during emergencies. The permit is contingent upon precautions as to water treatment and quality specified by the New York State Department of Health. Enlarging the capacity of the pumping station and connection to the aqueduct would be a relatively simple means of increasing the New York City water supply. Larger withdrawals from the Hudson River might aggravate the salt-water problem, and would increase the proportion of "emergency" Hudson River water in the city reservoir system. As in the other projects discussed subsequently, approval by the Water Resources Commission and New York State Department of Health would be needed.

Water Quality. Any consideration of using the Hudson River at Chelsea as a supplementary source of New York City's water supply must include recognition that the chloride content resulting from tidal influence is a highly significant factor in river-water quality. Intrusion of high-chloride sea water is influenced by tidal stages and rates of fresh-water flow.

As increase in the flow of fresh water will move the salt front downstream and, conversely, a reduction of the flow rate will allow salt water to move upstream. It is recognized that at any given location along the river the chloride content of the river water is not the same at all stages of the tide and at all points in the cross-section of the river. A chloride content of 50 mg/L (milligrams per liter) or less at mid-tide, mid-channel, and mid-depth has been adopted as an index for identifying the periods during which the river may be used at a given location as a source of water supply. This value has been selected to ensure that the maximum chloride content during such periods will be within acceptable limits.

Results of analysis of samples taken from the Hudson River in the vicinity of Chelsea indicate that water-quality characteristics other than chloride content are also affected by river flow and that, in general, the highest quality of water has been available during the periods of highest river flows. Data obtained for this study and from other studies indicate that with adequate treatment Hudson River water can be used safely to supplement the New York City supply.

River Water Availability. The following tabulation indicates approximately the number of days on which the chloride content index of the river at Chelsea could be expected to be 50 mg/L or less, on the basis of withdrawing 200 mgd. In general, pumping would be limited to the winter and spring seasons of the year.

Water year ending September 30	Number of days suitable for withdrawal of 200 mgd. from the Hudson River
1962	210
1963	120
1964	145
1965	115
4-year average	150

Pending further studies, a 200-mgd. rate appears to be the reasonable upper limit for withdrawals.

Required Degree of Treatment. The treatment required is that recommended in our report to the Board of Water Supply titled "Need for Additional Treatment of Hudson River Water as a Result of Increasing Capacity of Hudson River Pumping Plant," dated January 14, 1966. Treatment consists of break-point chlorination and coagulation with alum. Chlorination is provided to ensure satisfactory kill of bacteriological organisms. Feeding alum helps to reduce color, turbidity, and the phosphate content of the Hudson River water. As at present, chemically-treated water would be routed through the West Branch and Kensico Reservoirs, where several days of effective detention would allow settling of the floc resulting from chemical treatment and removal of other settleable solids from the water.

Existing Facilities. The major elements in the present 100-mgd. capacity pumping plant at Chelsea include approximately 850 ft. of 72-in. diameter reinforced-concrete intake from an intake crib in the river to a pump suction well, six vertical turbine pumps mounted in the well, and approximately 500 ft. of 54-in. diameter steel force main from the pumping station to a discharge connection to Shaft 6 of the Delaware Aqueduct. Facilities are provided in the pumping building for feeding chlorine and alum to the water.

Shaft 6 as originally constructed provided for high-pressure blowoff and drainage of the aqueduct. The existing Chelsea force main is connected to the top of the 48-in. blowoff riser pipe. The riser shaft extends to an elevation of 600 ft. below sea level, where a short horizontal tunnel connects to the aqueduct.

New Facilities. As shown on Fig. 6, increasing the capacity to 200 mgd. would require the installation of a second 100-mgd. pumping station, new 72-in. intake pipe, 54-in. force main, and riser shaft. About 1,000 ft. of force main would be required to carry flow from the new pumping station to the head of a new riser shaft adjacent to existing Shaft 6. Limited space in the existing shaft would necessitate construction of the new shaft down to El. -600. A short horizontal tunnel would join the new shaft to the present tunnel that connects Shaft 6 to the aqueduct. An additional 650 ft. of 54-in. main would be installed in the new riser shaft and tunnel to connect to the aqueduct.

Connection of the new force main would require blowoff and pumping out of the aqueduct. It is estimated that this

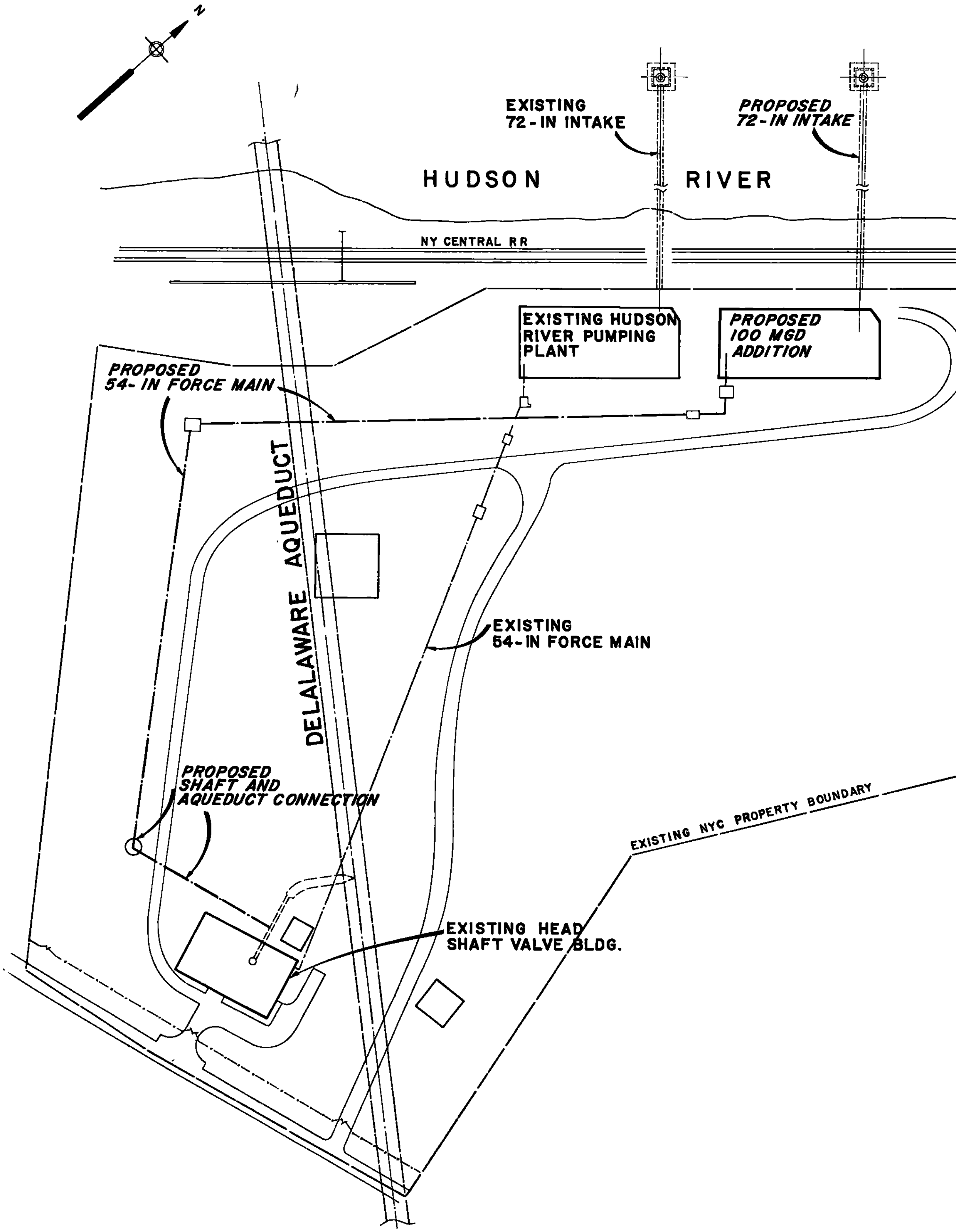

FIG. 6 HUDSON RIVER PUMPING PLANT ADDITION

operation might require taking the aqueduct out of service for as long as 30 days.*

Cost Estimate. To increase the capacity of the Chelsea Pumping Station from 100 mgd. to 200 mgd., including additional facilities for water treatment, would cost approximately $8,300,000, as shown in Appendix Table B-1. This estimate, and all others presented in the report, include an allowance of 20 percent for engineering and contingencies. Debt service in all cases has been estimated on the basis of 30-year bonds bearing 4-1/2 percent interest and level annual payments covering interest and amortization. No allowance has been made in annual costs for real estate taxes.

The enlarged Chelsea Pumping Station, and other project considered in the report, would be used only when necessary to augment the regular supply to avoid a water shortage. For this reason, it is impractical to estimate average annual costs. In each case, we have estimated the debt service and fixed operating expenses that would need to be met every year whether or not the supplementary supply was used. We have estimated also the additional variable operating costs that would be incurred when the water was taken and the total cost per million gallons for a year such as 1965, the driest year of the recent drought.

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*Consultants engaged by the Board of Water Supply to study the feasibility of increasing the capacity of the existing plant have furnished preliminary information on a plan that would utilize the existing shaft and not require that the aqueduct be taken out of service. This alternative would cost approximately $6,000,000, but involve greater pumping costs, and result in a unit cost of water not greatly different than shown in this report.

For a 100-mgd. addition to the Chelsea Pumping Station, the estimated costs are as follows:

Annual debt service and fixed operating costs	$ 762,000
Variable operating costs for driest year	469,000
Total cost for driest year	$1,231,000
Estimated yield during driest year, million gallons	11,500
Equivalent daily average yield in driest year, million gallons per day	32
Total cost per million gallons	$107

Westchester County Local Development

Local water supplies in Westchester County consist of wells and surface supplies. Appendix Tables A-1 and A-2 indicate the quantity of water obtained from these two sources during the past five years. The amount obtained from local sources has been relatively constant, averaging 29.8 mgd. in 1948 and 28.3 mgd. in 1964. The yield of local supplies was greater in wet periods and exceeded 35 mgd. in 1958. Surface supplies accounted for 25.3 mgd. in 1964, including 5.8 mgd. obtained from Connecticut for Port Chester. Port Chester, Yonkers, and Peekskill used 70 percent of the total. Ground-water production totaled 3.0 mgd., divided principally among ten small communities. Efforts to increase local supplies have not been successful and most communities have ultimately relied on New York City. The quantity of water purchased from New York City has increased from 20.2 mgd. in 1948 to over 78 mgd. in 1964.

Except for New York City's Croton system, surface waters, whether used for water supply or recreation, are distinctly limited in Westchester County. Byram Lake, now used by Mt. Kisco, is too small to be considered and the lower part of Byram River has been developed by the Greenwich Water Company and is not available.

Many lakes in the Croton watershed, with a total area of 3.6 square miles, are used chiefly for recreation and could be used as reservoirs only by the installation of pumping stations. If these lakes were so developed, the storage available would be 3,000 million gallons or less and the yield would be insignificant in comparison with water demands of New York City and Westchester County. For these reasons and because of the population concentrations around the lakes, these lakes should be considered for water supply purposes only in dire circumstances.

While a great many wells have been drilled in Westchester County, the majority of them are rock wells for individual households, yielding 5 gpm. (gallons per minute) or less. There appears to be little hope of developing any significant additional public supply from ground-water sources in the county.

Expansion of the Croton System

The Croton watershed is highly developed and, outside of a small increase in emergency supply described in the previous section, the only means of increasing the output of the system appears to be by pumping into it from outside sources.

It would be possible to increase the capacity of Croton Reservoir by installing droppable flashboards on New Croton Dam. Following the 1955 floods and resulting cracking of the dam, the permanent crest was lowered to El. 196 (Croton Datum). At this crest elevation, it was felt safe to pass a flood head of 7 ft. If 5-ft. high droppable flashboards had been in place prior to the recent drought, an additional 3,600 million gallons could have been stored. If this additional storage were used over a 4-year period, the added yield would be only 2.5 mgd.; if used over one year, the yield would be increased only about 10 mgd. The cost of flashboards and the concern for the safety of the dam following the 1955 damage make consideration of adding flashboards unwarranted.

The storage available in the Croton system could be used more effectively by providing a bypass around the Cross River Reservoir hydropump. This station was provided to pump water at a 30-mgd. rate from Cross River Reservoir into the Delaware Aqueduct. Actually, during drought years Cross River storage is often depleted. The reservoir has a flow line below the Delaware Aqueduct gradient and could be filled through such a bypass from the aqueduct whenever excess water was available. Construction of the bypass would be relatively inexpensive and appears desirable.

Floodwater Skimming - Westchester, Putnam, and Dutchess Counties

The New York City-Westchester County water supply could be increased by diverting excess flows from several streams lying east of the Hudson River and north of the Croton watershed

into the New York City system. The facilities contemplated for each would consist of a diversion structure on the stream, a pumping station, a transmission main, and, in some instances, chlorinating facilities.

Diversion sites have been selected on the Ten Mile River, which is tributary to the Housatonic River, and on the Fishkill and Wappinger Creeks, which are tributary to the Hudson River.

It is anticipated that the diversion works would be operated only during the winter and spring periods of high runoff and that even during these periods a predetermined minimum flow would be released to the stream below the diversion works. The magnitude of releases would depend upon downstream riparian needs and cannot, therefore, be determined at this time. However, for the purposes of this report, a minimum flow of 0.5 cfs. (cubic feet per second) per square mile has been adopted and only stream flows in excess of this rate have been considered available for diversion. This value is considerably greater than the summer dry-weather flows of the streams under study.

The facilities required for each of the possible diversions are shown in outline on Fig. 7 and are described below.

Ten Mile River. The Ten Mile River is a branch of the Housatonic River. Its watershed lies immediately to the north of the Croton watershed and adjacent to the New York-Connecticut boundary. Although the stream rises and terminates in Connecticut, most of its length and watershed lie within the State of New York.

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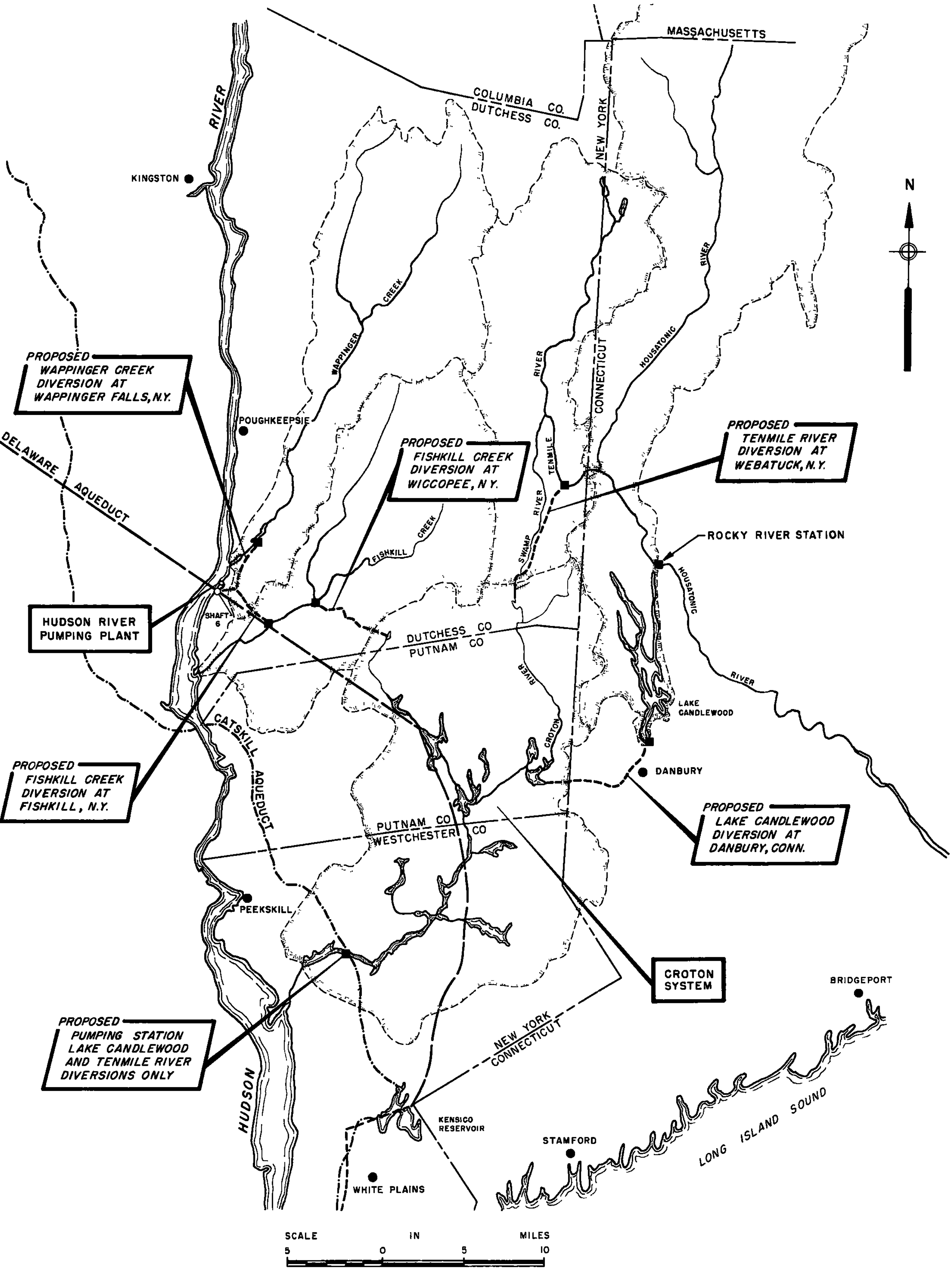

FIG. 7 FLOOD SKIMMING SITES EAST OF HUDSON RIVER

The diversion works have been assumed to be located at the Village of Webatuck, where the drainage area is about 195 square miles. The facilities would consist of a low diversion weir and a pumping station located on the south bank of the river. A 43,500-ft. long transmission main would be constructed along Route 55 from the pumping station to Wingdale and thence southward and parallel to the Swamp River. The main would continue southward to the Village of Pawling, where it would cross the divide into the Croton watershed and discharge into the East Branch of the Croton River. A static lift of only about 120 ft. would be needed.

The facilities described above would deliver water into New York City's low-level Croton supply system and not into the high-level Delaware-Catskill system. To make the plan comparable to other alternates, a second pumping station would be needed to lift the water from either New Croton or Croton Falls Reservoir into the Catskill or Delaware Aqueduct. The pumping lift for this station would be approximately 190 ft.

As a result of a study of the capital and operating costs of the above facilities for various maximum capacities, a 300-mgd. station and an 84-in. diameter transmission main have been selected for the primary lift from the Webatuck site.

The construction cost of the above facilities is estimated at $22,000,000, as shown in Appendix Table B-2.

Fixed and operating costs have been estimated as follows:

Annual debt service and fixed operating costs	$1,465,000
Variable operating costs for driest year	325,000
Total cost for driest year	$1,790,000
Estimated yield during driest year, million gallons	6,550
Equivalent daily average yield, million gallons per day	18
Total cost per million gallons	$274

Fishkill Creek. As shown on Fig. 7, the Fishkill watershed lies immediately to the north of the Croton and to the west of the Ten Mile River watershed. The watershed comprises an area of about 190 square miles, all of which lies within New York State. The stream flows southwestward to discharge into the Hudson River at Beacon, New York. Its entire 25-mile length lies within Dutchess County.

Two alternate points of diversion have been studied. The Wiccopee Creek site is just below the confluence of Fishkill Creek and Wiccopee Creek and has a drainage area of 151 square miles. A diversion weir at this point would permit pumping through a pipeline or pipeline and tunnel to discharge into a tributary of the Boyd Corners Reservoir. Pumping rates up to 350 mgd. appear possible, but a 200-mgd. installation has been selected tentatively as the most economical size. The transmission line could be entirely of pipe, but, to avoid excessively high pumping heads and the possible need for repumping, it appears more reasonable to use a combination of 24,700 ft. of 84-in. pipe and 5,600 ft. of tunnel.

The construction cost of the above facilities is estimated to be $22,000,000, as shown in Appendix Table B-3.

Estimated fixed and operating costs are as follows:

Annual debt service and fixed operating costs	$1,420,000
Variable operating costs for driest year	360,000
Total cost for driest year	$1,780,000
Estimated yield during driest year, million gallons	7,225
Equivalent daily average yield, million gallons per day	20
Total cost per million gallons	$246

A diversion could also be made near the Village of Fishkill about 3-1/2 miles downstream from Wiccopee Creek. At this point the drainage area is 157 square miles. This site is adjacent to Shaft 7 of the Delaware Aqueduct. Because Shaft 7 was a construction shaft and is not suitable for introduction of water, it would be necessary to pump water through a 21,000-ft. long pipeline to Shaft 6. There the water would be introduced through a new shaft in the manner previously described under Hudson River Pumping Plant Addition. This pipeline would be 72 in. in diameter. The present studies have been based on a 200-mgd. pumping rate.

Construction cost of the Fishkill site development is estimated to be $15,000,000, as shown in Appendix Table B-4.

Fixed and operating costs for this project are estimated to be as follows:

Annual debt service and fixed operating costs	$ 979,000
Variable operating costs for driest year	334,000
Total annual cost for driest year	$1,313,000
Estimated yield during driest year, million gallons	7,450
Equivalent daily average yield, million gallons per day	20
Total cost per million gallons	$177

Diversion from the Fishkill Creek to New York City is presently prohibited by statute reserving these waters to mills within Dutchess County for the production of power. Although the requirements of the law appear obsolete, action of the State Legislature would be required before water could be diverted to New York City.

Wappinger Creek. A supply from Wappinger Creek could be developed at a site near the upper end of Wappinger Lake and pumped to Shaft 6 for introduction into the Delaware Aqueduct. The drainage area of the creek is about 182 square miles at the point selected. The project has been studied on the basis of pumping at a rate of 200 mgd. through a 72-in. pipeline 25,300 ft. long.

The construction cost of the above facilities is estimated to be $19,000,000, as shown in Appendix Table B-5.

Corresponding debt service and operating costs for this project are as follows:

Annual debt service and fixed operating costs	$1,222,000
Variable operating costs for driest year	308,000
Total annual cost for driest year	$1,530,000
Estimated yield during driest year, million gallons	4,675
Equivalent daily average yield, million gallons per day	13
Total cost per million gallons	$328

The legal restriction on the removal of water from Dutchess County applies to Wappinger Creek as well as Fishkill Creek.

Housatonic River - Candlewood Lake

Use of Housatonic River water for a New York City supply has been considered in the past, with most attention given to the Ten Mile River, a tributary lying largely in New York State. Development of the Housatonic River itself or tributaries in Connecticut has not been considered seriously because of anticipated interstate and hydropower conflicts. During the current drought period, however, the possibilities have been raised again, including emergency use of Candlewood Lake water.

Candlewood Lake is an artifical reservoir created by the Connecticut Light and Power Company in 1928 as a pumped storage project. The lake is filled by pumping from the Housatonic River at the Rocky River Station. It has a useful capacity of 46.5 billion gallons and a normal flow line at El. 430.

Use of Candlewood Lake as a water supply is predicated upon being able to make suitable arrangements with the Northeast Utilities Service Company, the State of Connecticut, and other potential downstream water users.

The runoff of the Housatonic River at the Rocky River Station averages more than 1,000 mgd. and in the 1965 water year exceeded an average of 380 mgd. By pumping during periods of excess stream flow, at least 300 mgd. could be transferred to Candlewood Lake. In a dry year such as 1965, the yield from such operation would be 37,000 million gallons, equivalent to 102 mgd.

A 250-mgd. pumping station would be required to transfer water from Candlewood Lake at El. 430 into a receiving pond at El. 465, from which it would flow into East Branch Reservoir. An 84-in. pipeline, 35,000 ft. long, 3,500 ft. of tunnel, and an open channel 4,700 ft. long would be required. In order to lift the water to New York's high-level system, an auxiliary pumping station would be built either at Croton Falls, to discharge into the Delaware Aqueduct, or at Croton Reservoir, to discharge into the Catskill Aqueduct.

The construction cost of the Candlewood project is estimated to be $20,000,000, as shown in Appendix Table B-6.

Fixed charges and operating costs for this project are estimated as follows:

Annual debt service and fixed operating costs	$1,410,000
Variable operating costs for driest year*	950,000
Total cost for driest year	$2,360,000
Estimated yield during driest year, million gallons	37,000
Equivalent daily average yield, million gallons per day	102
Total cost per million gallons	$64*

Annual operating costs for the project include only those for the proposed facilities. Compensation to the power company for the use of its facilities and/or its losses in revenue due to reduced hydrogenerating capacity would be established by negotiation and are not included.

Other Possible Developments. Major developments of streams east of the Hudson River have been studied in the past for addition to the New York-Westchester County supply systems. These projects would be more comprehensive than the flood-skimming plans and would involve large impoundments and long aqueducts. They have not been studied in this preliminary review, but will be included as part of the over-all study.

Catskill Flood Skimming

New York City's Catskill water supply system comprises 571 square miles of drainage area, two reservoirs with a combined capacity of 150 billion gallons, and the Catskill Aqueduct extending 75 miles to Kensico Reservoir in Westchester County. As shown on Fig. 5, Ashokan Reservoir intercepts the flow of

*Excluding compensation to power company.

Esopus Creek; Schoharie Creek water reaches Ashokan through the Shandaken tunnel and Esopus Creek. The Schoharie Reservoir is relatively small (19 billion gallons) and serves essentially as a diversion pool for the tunnel. The Catskill Aqueduct has a capacity of 620 mgd. It is a gravity conduit not designed to withstand internal pressure, except for river and stream crossings.

The Catskill reservoirs have not filled during the recent drought, and the deficiency in storage reached 60 billion gallons in 1965. Two projects have been investigated that would extend the Catskill drainage area and reduce the depletion of the reservoirs during long dry periods. Both involve the diversion of floodwaters that now escape unused to the Hudson River.

Rondout Creek. The Catskill Aqueduct passes under Rondout Creek near High Falls (see Fig. 8). The drainage area of Rondout Creek at this point is 400 square miles, of which only 95 square miles are intercepted by Rondout Reservoir.* Runoff from 305 square miles between the reservoir and the Catskill Aqueduct crossing is used by the Central Hudson Gas & Electric Corporation at the High Falls hydroelectric plant, but has not been developed for water supply purposes.

Under the project proposed, water would be diverted only during periods of high flow, chiefly in the winter and spring. In estimating the available yield, it has been assumed

*Rondout Reservoir was built as part of the Delaware River System and is considered part of that system, although Rondout Creek flows into the Hudson River.

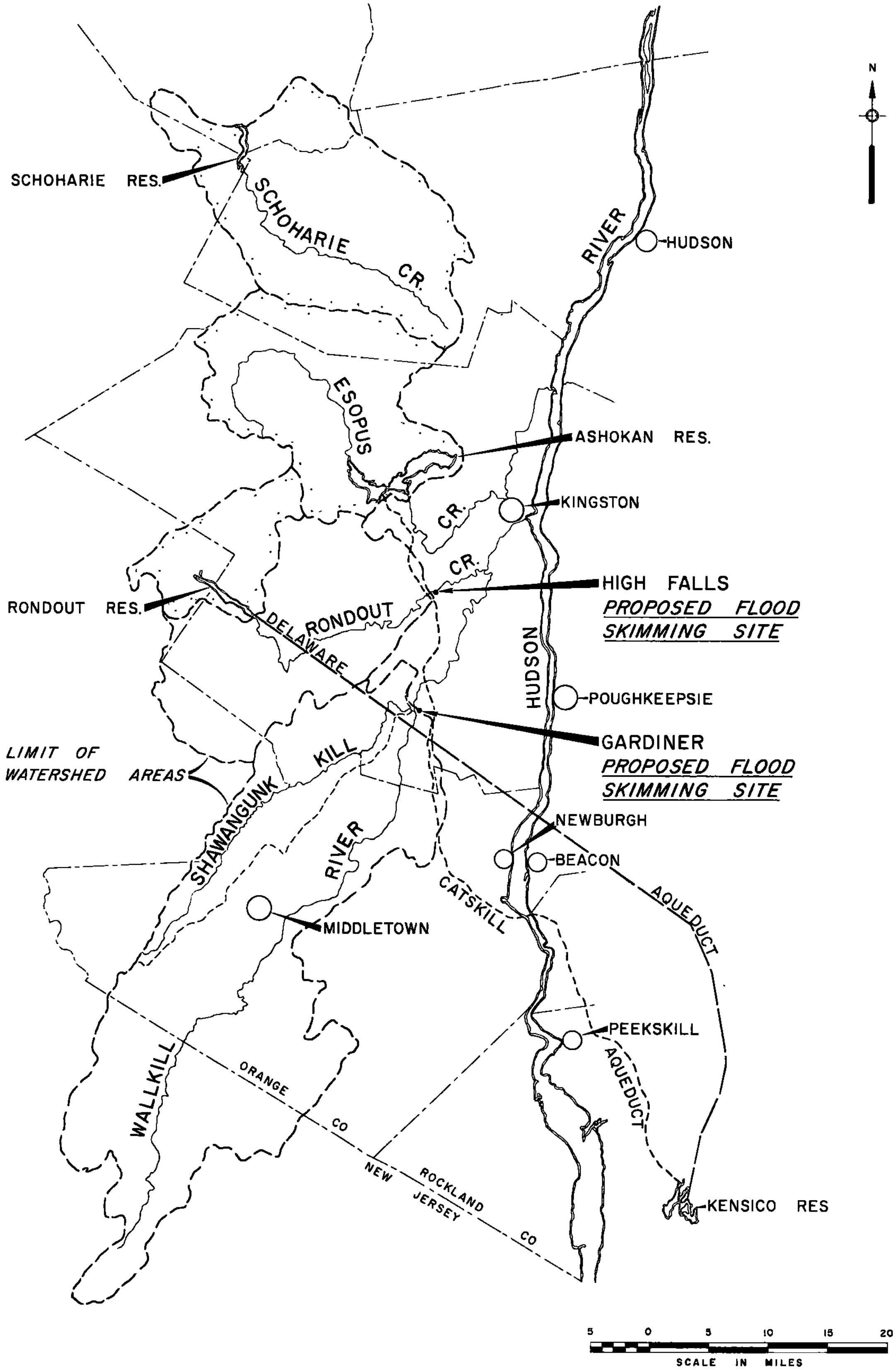

FIG. 8 CATSKILL WATERSHED FLOOD SKIMMING SITES

that no water would be pumped when the Rondout flow dropped below 0.5 cfs. per square miles of drainage area, or approximaterly 100 mgd. at the diversion works. Allowing for this and for the fact that the High Falls plant is not large enough to utilize flood flows fully, compensation due the Central Hudson Gas & Electric Corporation for loss in power generation should be small.

The Rondout facilities (see Fig. 9) would include diversion works on the creek two miles southwest of High Falls in the vicinity of the Catskill Aqueduct crossing, a 500-mgd. pumping station, and 10,000 ft. of 10-ft. diameter force main between the pumping station and the aqueduct shaft at the downstream end of the Rondout Creek pressure tunnel. According to daily flow records, these facilities on Rondout Creek could have increased the 1965 water supply by 25,600 million gallons. The pumping station would have operated a total of 194 days, and at the maximum 500-mgd. rate on 15 days.

The Rondout facilities are estimated to cost $21,000,000, as shown in Appendix Table B-7, tentatively based on the use of diesel engine-driven pumps.

Fixed and operating costs have been estimated as follows:

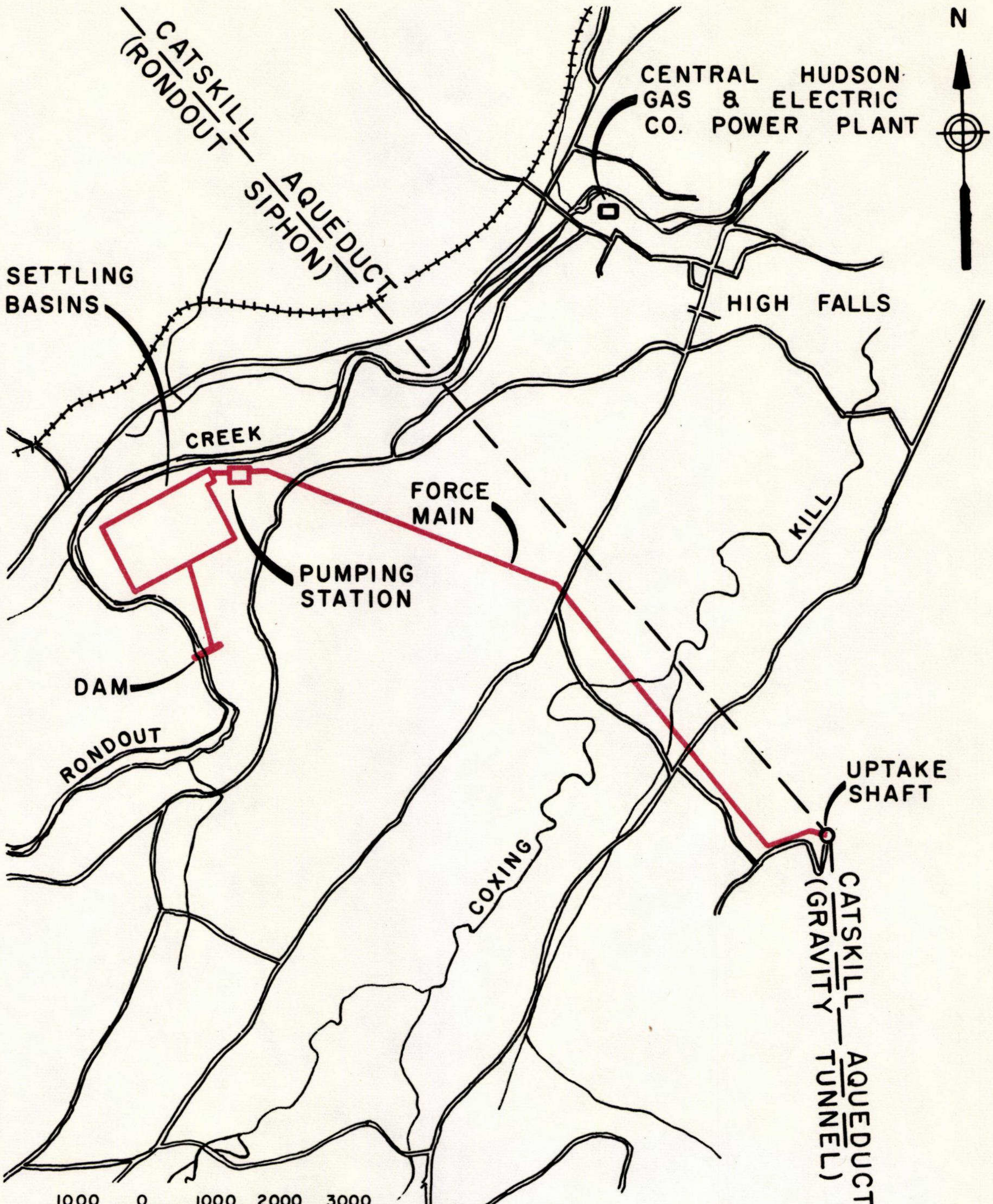

FIG. 9 RONDOUT FLOOD SKIMMING PROJECT

Annual debt service and fixed operating costs	$1,430,000
Variable operating costs for driest year	500,000
Total cost for driest year	$1,930,000
Estimated yield during driest year, million gallons	25,600
Equivalent daily average yield, million gallons per day	70
Total cost per million gallons	$75

Wallkill River. The Wallkill River project (see Fig. 10) would include diversion works approximately one mile above the confluence of the Wallkill River and Shawangunk Kill, a 500-mgd. diesel-powered pumping station, and 10,000 ft. of 10-ft. diameter force main discharging into the Catskill Aqueduct near Gardiner, where the Catskill and Delaware Aqueducts cross. The Wallkill River watershed tributary to the diversion works is approximaterly 600 square miles.

If Wallkill River diversion facilities had been available, approximately 33 billion gallons could have been pumped from the river into the New York City system during 1965. Pumping would have been required on approximately 100 days. During 19 of these days the pumping station would have operated at full capacity. All of these figures are based upon the assumption that no water would be diverted when the stream flow was less than 0.5 cfs. per square mile, or some 195 mgd. at the diversion works.

This site was selected in preference to one farther downstream in order to take advantage of facilities provided

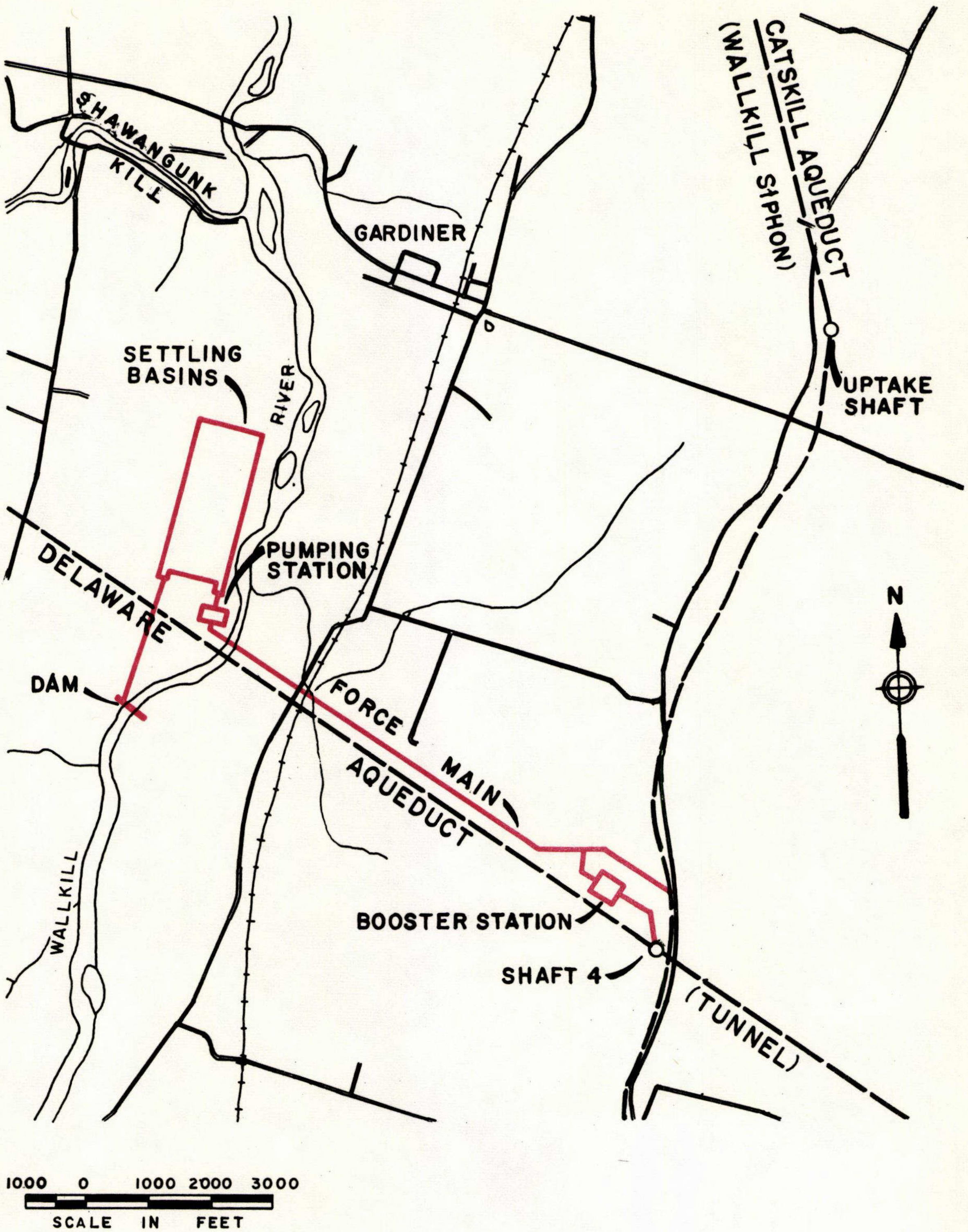

FIG. 10 WALLKILL FLOOD SKIMMING PROJECT

at Shaft 4 when the Delaware Aqueduct was built for interconnecting the two aqueducts. However, the hydraulic grade line of the Delaware Aqueduct is 310 ft. higher than the Catskill Aqueduct at the crossing and a booster pumping station would be needed to deliver Wallkill River water into the Delaware Aqueduct.

If both the Wallkill and Rondout projects were built, the combined output of the two pumping stations frequently would exceed the 620-mgd. capacity of the Catskill Aqueduct and some of the water would have to be pumped into the Delaware Aqueduct.

The cost of the project is estimated at $21,000,000, plus $13,000,000 if the booster pumping station and connection to the Delaware Aqueduct are included (see Appendix Tables B-8 and B-9).

Fixed and operating costs for the Wallkill facilities without a booster station have been estimated as follows:

Annual debt service and fixed operating costs	$1,445,000
Variable operating costs for driest year	630,000
Total cost for driest year	$2,075,000
Estimated yield during driest year, million gallons	33,000
Equivalent daily average yield, million gallons per day	90
Total cost per million gallons	$63

Addition and operation of the booster station would increase this cost by $45 per million gallons.

Other Possibilities. Steps to increase the Schoharie Creek supply have not been studied in this preliminary review. As noted earlier, Schoharie Reservoir is small in comparison with its watershed. Water is sometimes lost over the spillway even when Ashokan Reservoir is not full because the Shandaken Tunnel cannot divert the water fast enough. This could be corrected by the construction of a second reservoir on Schoharie Creek, as proposed by the Board of Water Supply years ago, by a second gravity tunnel, by a pumping station ahead of the present tunnel to increase its capacity, or some combination of these methods. Previous studies have indicated a potential increase in yield between 55 and 95 mgd., and the possibilities will be explored in the final report.

Delaware Watershed - Flood Skimming

Beaver Kill and Willowemoc Creek Floodwater Diversions. Although New York City impounds the runoff from some 915 square miles in the Delaware River watershed, much water still escapes unused to the sea during heavy spring flows and floods. Early plans for the city's Delaware River system included impoundment of 170 square miles of drainage area on the Little Delaware, Beaver Kill, and Willowemoc Creek in addition to Pepacton and Neversink Reservoirs. These smaller impoundments were eliminated as a result of the first U. S. Supreme Court decree in 1931. Water from the Little Delaware is now impounded in the Cannonsville Reservoir, but the other two streams have not been developed.

In an effort to alleviate water shortages in recent years, the Board of Water Supply has explored the feasibility of tapping floodwaters in these streams, and has taken the matter up informally with the New York State Water Resources Commission, the Delaware River Basin Commission, and the Corps of Engineers. Three diversion sites have been considered:

	Drainage area, square miles
Beaver Kill at Shaft No. 1, East Delaware Tunnel	60
Beaver Kill at Shaft No. 4, West Delaware Tunnel	96
Willowemoc Creek at Shaft No. 6, West Delaware Tunnel	42

These drainage areas, their relation to New York's water supply facilities, and the Delaware tunnels are shown on Fig. 11. Since the tunnels have shafts at each of the three stream crossings and the water levels in the tunnel are substantially below the creek beds, flood flows could be diverted by gravity. Furthermore, the hydraulic gradient is such that the diverted water could be made to flow downstream through the tunnels to Rondout Reservoir, or upstream to Pepacton or Cannonsville.

We have investigated the flows of the Beaver Kill between 1938 and 1965, with particular attention to the past four dry years, and have drawn the following conclusions:

1. Diversion of flood flows from Beaver Kill into Shaft No. 4 of the West Delaware Tunnel

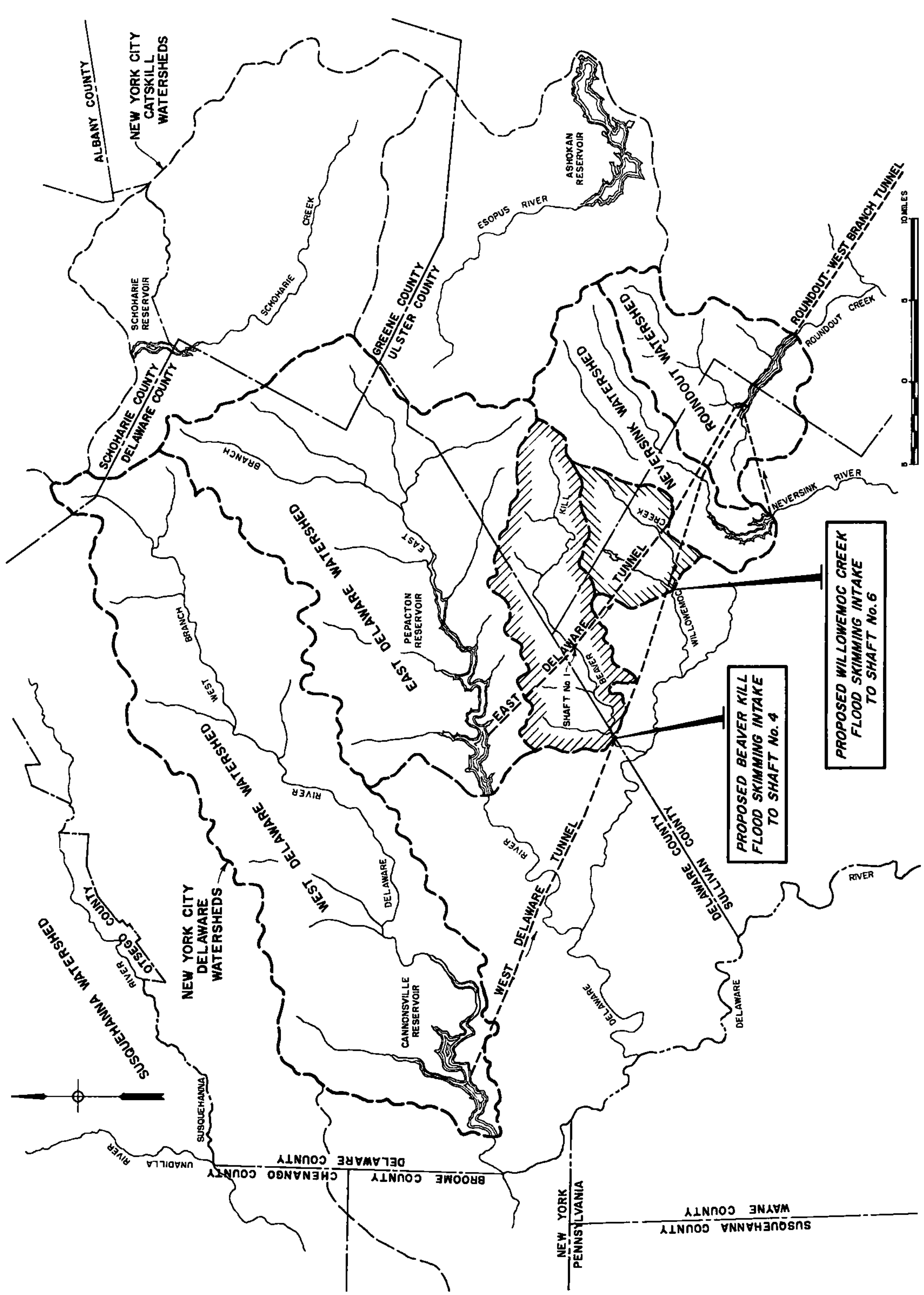

FIG. 11 DELAWARE WATERSHED FLOOD SKIMMING SITES

would yield between 10 and 30 billion gallons during a dry year like 1965, depending upon the size of downstream releases needed to satisfy lower riparian owners. If diversions were limited to provide downstream flows of at least 0.5 cfs. per square mile of drainage area intercepted, the yield would be 22 billion gallons for the year. With larger downstream releases, the yield would be less: 20 billion gallons at 0.66 cfs. per square mile, 16 billion gallons for 1.0 cfs. per square mile.

2. Economical diversion of floodwaters from a stream requires that the water be captured when it is available and be led off to storage at a high rate. In this instance, diversion capacity of 1,000 cfs. would develop most of the potential yield and it would not pay to provide greater capacity. Diversion works and a connection to the aqueduct of 1,000-cfs. capacity could be built conveniently at Shaft No. 4.

3. Diversion of 18 to 20 billion gallons during 1965 would not have reduced the winter and spring flows of the Delaware River at Montague below the limits established in the U. S. Supreme Court decree.

<u>Beaver Kill Flood Skimming, Shaft No. 4, of West Delaware Tunnel.</u> The works at Shaft No. 4 would include control gates

across Beaver Kill for maintaining prescribed downstream flows, an intake weir to a settling pond, a connection to Shaft No. 4, and a release weir from the pond for flows in excess of diversion capacity. As shown on Fig. 12 and 13, we propose a separate intake drop shaft and tunnel connection to Shaft No. 4 in order to minimize the risk of damage to existing works and interruption of service. The diversion pond is intended for the removal of sand and gravel found in creek water during flood flows and for equalizing flows into the shaft. The pond, weirs, gates, and connection are arranged to provide easy and accurate control of flow rates. Detailed engineering might suggest modifications and improvements, but the project outlined is adequate to illustrate the design concept. The diversion works at Shaft No. 4 are estimated to cost approximately $5,000,000, as summarized in Appendix Table B-10.

For the Beaver Kill flood-skimming project, fixed and operating costs are estimated as follows:

Annual debt service and fixed operating costs	$367,000
Variable operating costs for driest year	220,000
Total cost for driest year	$587,000
Estimated yield during driest year, million gallons	18,250
Equivalent daily average yield in driest year, million gallons per day	50
Total cost per million gallons	$32

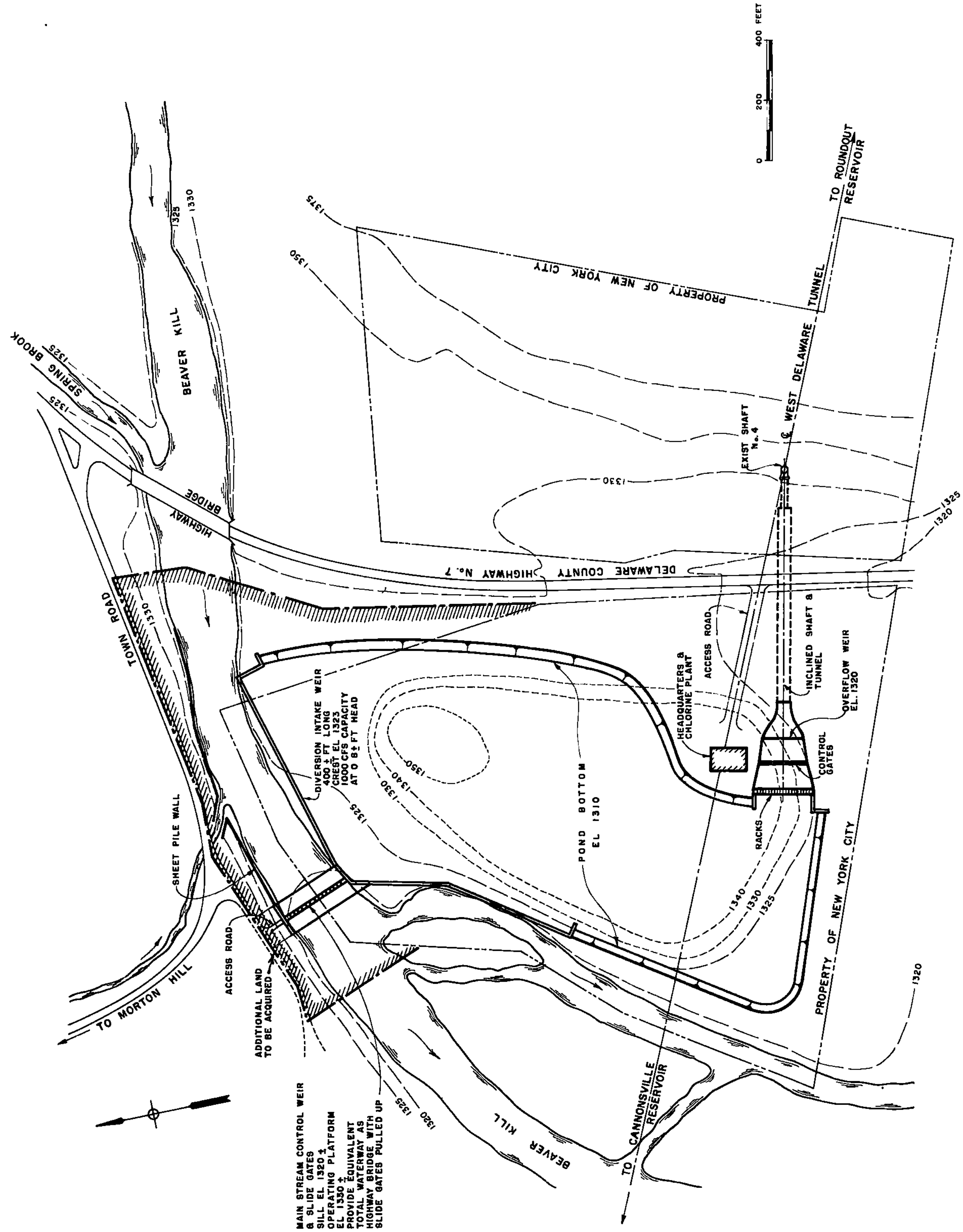

FIG. 12 BEAVER KILL FLOOD SKIMMING PROJECT - PLAN

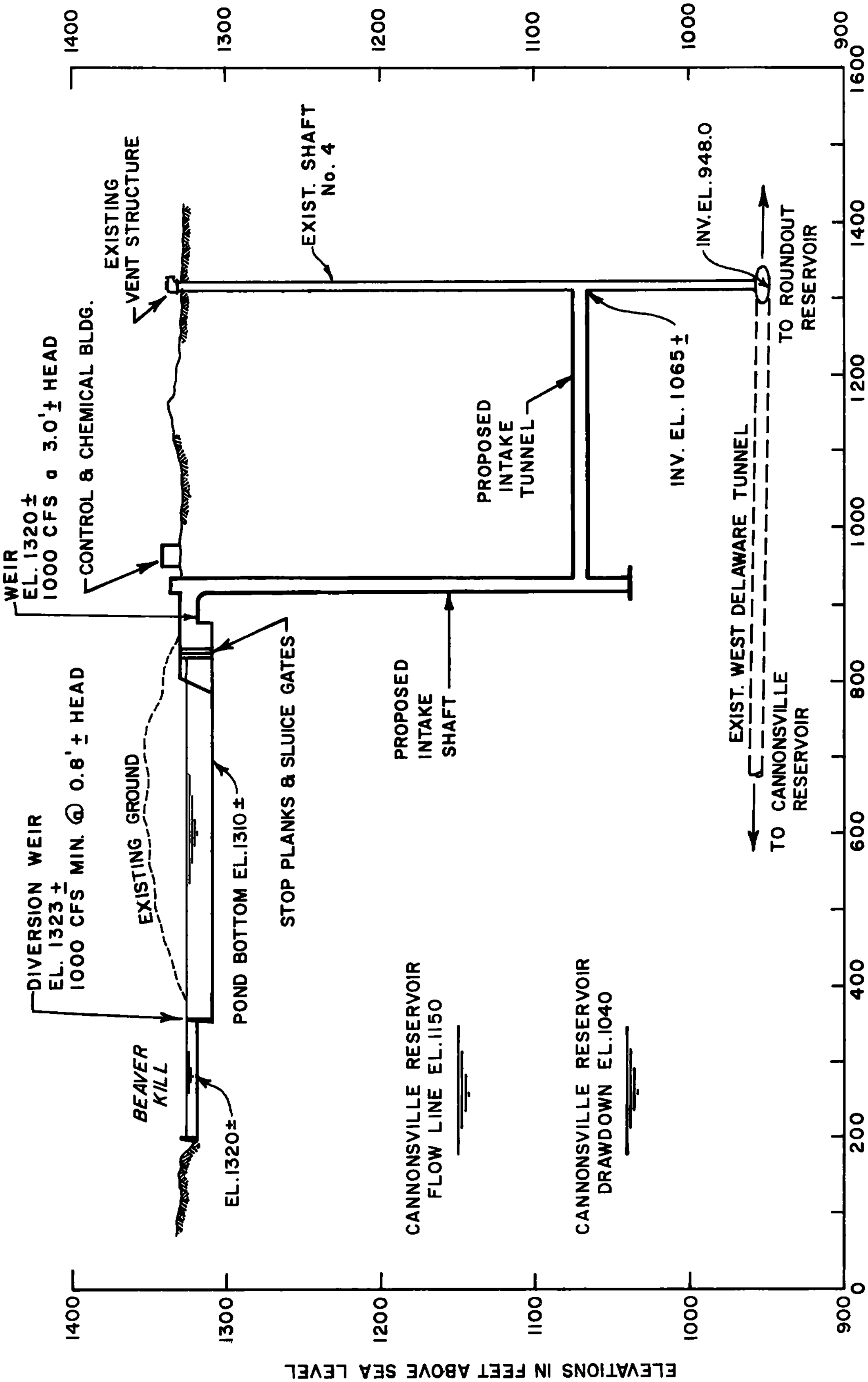

FIG. 13 BEAVER KILL FLOOD SKIMMING PROJECT - PROFILE

Diversion of the Beaver Kill into Shaft No. 1 of the East Delaware Tunnel would cost fully as much and develop only 60 square miles. However, diversion to the East Delaware Tunnel would utilize the storage of the Pepacton Reservoir whose storage is larger in proportion to drainage area than that of Cannonsville. This project will be given further consideration in our study of system yield and operation to be presented in our final report.

Willowemoc Creek Flood Skimming, Shaft No. 6 of West Delaware Tunnel. Diversion works at Shaft No. 6, estimated to cost approximately $5,000,000 (see Appendix Table B-11), would intercept floodwaters from the 42-square mile Willowemoc Creek watershed and increase the yield in a dry year like 1965 by 4 to 12 billion gallons, depending upon the downstream release stipulation. Flood flows on the Beaver Kill and on Willowemoc Creek are likely to occur at the same time, and development of both watersheds would involve a combined diversion rate of approximately 1,500 cfs. This could be accommodated by splitting the flow in the West Delaware Aqueduct, some going downstream to Rondout Reservoir and some going upstream to Cannonsville.

For the Willowemoc Creek flood-skimming project, fixed and operating costs are estimated as follows:

Annual debt service and fixed operating costs	$367,000
Variable operating costs for driest year	135,000
Total cost for driest year	$502,000
Estimated yield during driest year, million gallons	7,300
Equivalent daily average yield in driest year, million gallons per day	20
Total cost per million gallons	$69

Legal Considerations. The feasibility of diverting floodwaters from the Beaver Kill and Willowemoc Creek would depend upon securing approval of the New York State Water Resources Commission and acquiescence of the States of New Jersey, Pennsylvania, and Delaware, and of the Federal Government, the fifth member of the Delaware River Basin Commission. The matter presumably would be taken up by New York through the Delaware River Basin Commission, and amendment to the U. S. Supreme Court decree might be necessary. The diversion facilities could be completed within two or three years, and would provide considerable relief at relatively low cost. Satisfying downstream interests and acquisition of permanent rights to the water, however, might take much longer.

Flashboards at Cannonsville Dam

Increasing available storage by constructing flashboards on the lower spillway at Cannonsville has been suggested as a means of increasing the available supply during dry years.

Specifically, it has been proposed to raise the flow line of the reservoir 8 ft., from El. 1,150 to El. 1,158, increasing the storage capacity of Cannonsville Reservoir from 97 to 110-1/2 billion gallons. Installation of metal gates for this purpose is estimated to cost approximately $500,000; inflatable rubber weirs some $150,000 less.

A study of storage depletion over the period 1961-66, assuming conditions of water conservation and relaxed Delaware River release requirements, indicates that additional Cannonsville storage could have been used to advantage in several drought years.

Long Island Ground Water

New York City Ridgewood Supply. When Brooklyn became part of New York City in 1898, its water supply was merged with the city system. The Brooklyn supply was drawn from a number of ponds and wells along the south shore of Long Island in Queens and Nassau Counties. The general location of the works is shown on Fig. 14. The sources between Ridgewood and the Milburn station was designated the "West Watershed;" those east of the Milburn station comprise the "East Watershed." In addition to the sources of supply, the Long Island facilities consisted of the Milburn and Ridgewood Booster Pumping Stations, a brick gravity conduit from Massapequa Pond to Ridgewood, two 48-in. cast-iron force mains between Milburn and Ridgewood stations, and a 72-in. steel transmission main from Massapequa to Ridgewood. The Long Island watershed diversion presently is maintained by the Department of Water Supply, Gas &

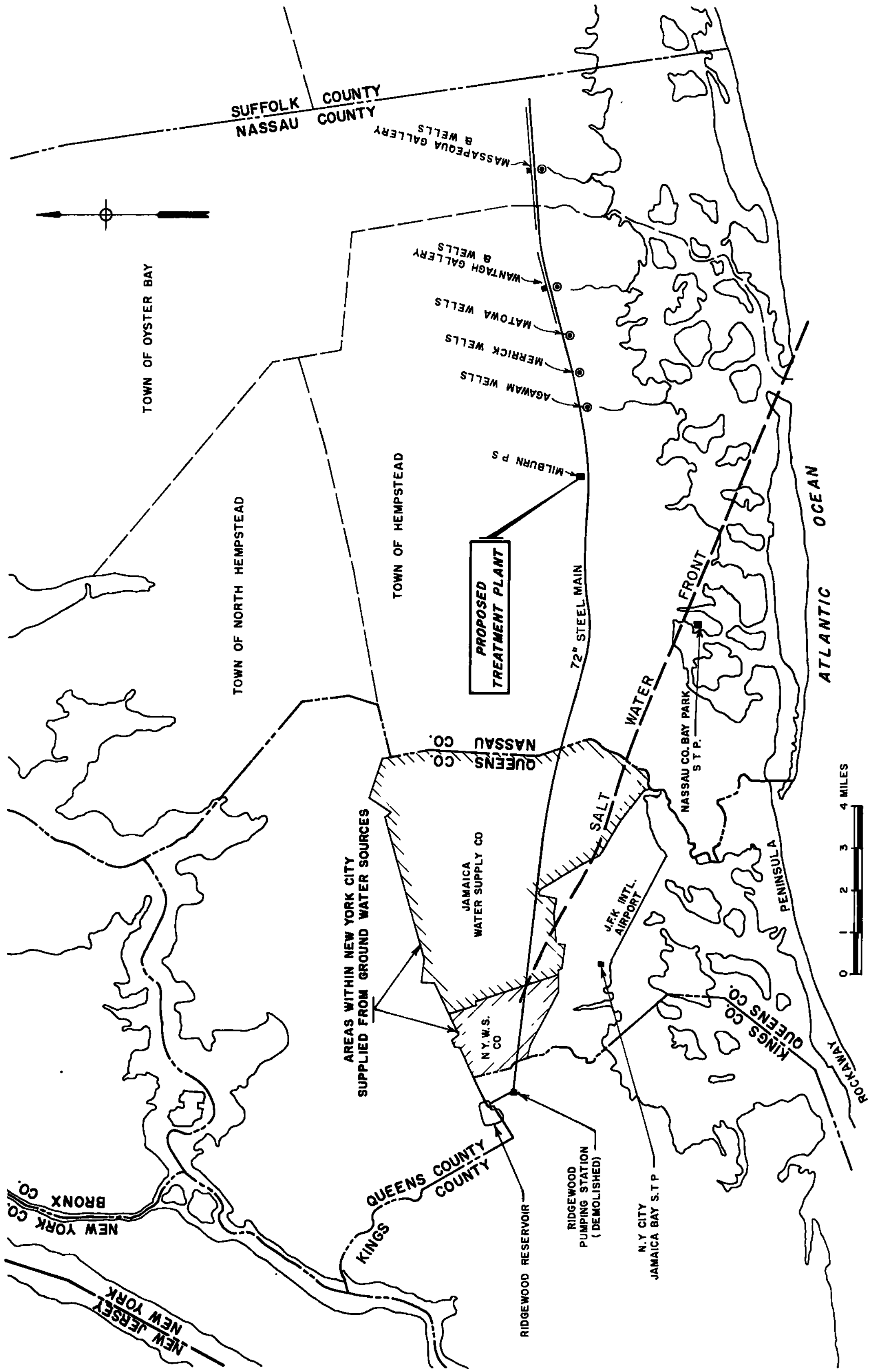

FIG. 14 LONG ISLAND GROUNDWATER – LOCATION PLAN

Electricity in ready reserve as a standby supply to the Rockaways and John F. Kennedy International Airport, and as an emergency source for the system at large.

Pumpage from these underground sources totaled 125 mgd. in 1915. It declined rapidly thereafter in favor of the Catskill supply, and since then the Long Island sources have been used intermittently. During the water shortage of 1949-50, the facilities were operated for 12 months and provided a total of 39 billion gallons, equivalent to an average of 107 mgd. In 1954, the city pumped 16 billion gallons (at rates of 34 mgd. from the East Watershed, 7 mgd. from the West Watershed, and 4 mgd. from wells in Queens). In 1965-66, approximately 6-1/2 billion gallons were drawn from the East Watershed over a 12-month period to alleviate the water shortage.

Investor-Owned Water Company Supplies in Queens. Nearly 700,000 residents of Queens are regularly supplied Long Island groundwater by the Jamaica Water Supply Company and New York Water Service Corporation. The sustained yield of the private water company systems totals 87 mgd., with a peak capacity of approximately 110 mgd. The city has been urged by customers of these two companies to take over these systems and to replace the ground water with water from upstate sources provided elsewhere in New York City. Poor water quality (including 300 to 600 mg/L hardness in some sections) and high water rates are the principal complaints.

Evaluation of these complaints, recommendations as to ultimate policy, and determination of works the city would have to build to serve the present customers of the two companies are beyond the scope of this report. It is clear, however, that so long as the city faces the possibility of water shortage, it cannot dispense with sources of supply that can furnish nearly 90 mgd. of potable water. We have assumed that the two companies will continue to operate for the time being at least. We recognize, however, that the poor water provided in some areas will not be tolerated indefinitely and that either treatment of the ground water or use of some other source of supply will be required in the near future.

Yield Available from New York City Ridgewood Sources. The West Watershed, extending from the Ridgewood Pumping Station to Hempstead Pond, cannot be used to increase the city's water supply. It is located in a section of Queens and Nassau Counties already suffering from overpumping. The ground water levels have been lowered and the saltwater front has moved inland slowly to its present location as shown on Fig. 14. Although the movement is slow, the hazards are well understood, and all agencies concerned with Nassau County water resources are working toward less pumping in this area. Furthermore, many of the city's facilities have been dismantled and a costly construction program would be needed to put the West Watershed back in operation. Hempstead Pond has dried up in the current drought.

The East Watershed, on the other hand, lies in an area of relatively light pumping, where the water table has not been depressed. It could be used effectively by the city for many years. Its value has been recognized by Nassau County officials, and for some years New York City has contemplated sale of the property to the county. We understand, however, that New York City has definitely put off selling these works to Nassau County until it completes the proposed new Third City Tunnel. The safe yield of the East Watershed has been estimated by various investigators at approximately 45 mgd. From our analysis of recent pumping and water level data this seems reasonable, but to be on the safe side we have used a figure of 40 mgd.

In estimating the yield of the East Watershed, we are mindful of forecasts that Nassau County will be out of fresh water within the next 30 or 40 years and before that time will have either to import water from beyond the county boundaries, desalt sea water, or reclaim sewage by elaborate treatment and recharge aquifers. We recognize, too, that if New York City uses regularly its Long Island sources, the water available for Nassau County will be 40 mgd. less. For the next two or three decades, however, there is no reason why New York City should not continue to use its Long Island resources, particularly in dry years when its upland resources are deficient. The East Watershed could be rehabilitated quickly and at relatively low cost. Even if the city anticipated that the works would be sold to Nassau

County in 20 or 30 years, or possibly abandoned, regular use of Long Island ground water in the meantime would help alleviate shortages in the immediate or near future.

The East Watershed surface ponds normally are not used as sources of water supply, and the adjacent land has been turned over to the Long Island State Park Commission. Abandonment of these surface sources would not reduce significantly the over-all yield, however, because the water would still be available through the wells and infiltration galleries. Experience has shown the ponds and ground-water resources to be one and the same, with pumpage from one causing a reduction in the other, and it is impossible to calculate separately the safe yield.

East Watershed Water Quality. Aside from the cost of maintaining the city's Long Island watersheds, a major objection to their continued use is poor water quality. The surface ponds are badly contaminated, and not truly safe even with extensive chlorination. The deterioration in bacteriological quality in recent years is shown clearly by the coliform data in Appendix Table C-1.

As shown in Appendix Table C-2, the ground water is of better sanitary quality, but is unsatisfactory with respect to color, turbidity, and mineralization. Iron normally exceeds 0.3 mg/L and frequently reaches 2 or 3 mg/L. Manganese ranges from 0.1 to 1.8 mg/L. Iron and manganese are particularly objectionable because they oxidize when mixed with air or chlorine bleach and are likely to stain laundry, plumbing fixtures, etc. At high concentrations, they also impart an unpleasant taste to the water. The higher coliform and ABS (alkyl benzene sulfonate) concentrations found in the gallery waters reflect pollution of the shallower aquifer.

Necessary Treatment. It is proposed that a treatment plant be installed at the Milburn Pumping Station to remove iron and manganese, and associated turbidity and color. Chlorinated ground water from the East Watershed would be delivered to the plant through the eastern end of the existing 72-in. steel main. Some rehabilitation or replacement of raw-water pumping equipment would be needed, and two of the three 25-mgd. low-lift pumps at Milburn might be converted to transfer pump service ahead of the treatment plant.

For treatment we propose aeration, chemical treatment, and fifteen 3-mgd. rapid-sand filters of the valveless type with self-contained washwater storage, plus chlorination. Activated carbon has helped to reduce ABS at Milburn and could be applied in the new plant if desirable. The treated water would be pumped from Milburn through the western section of the 72-in. main to the water distribution system at Ridgewood, in Brooklyn. Two new 10-mgd. high-lift pumps would be installed at Milburn to supplement the existing two 5-mgd. and two 10-mgd. units. A tentative layout of the facilities at Milburn is shown on Fig. 15.

Cost. The construction cost of the work is estimated at $10,000,000, as summarized in Appendix Table B-12.

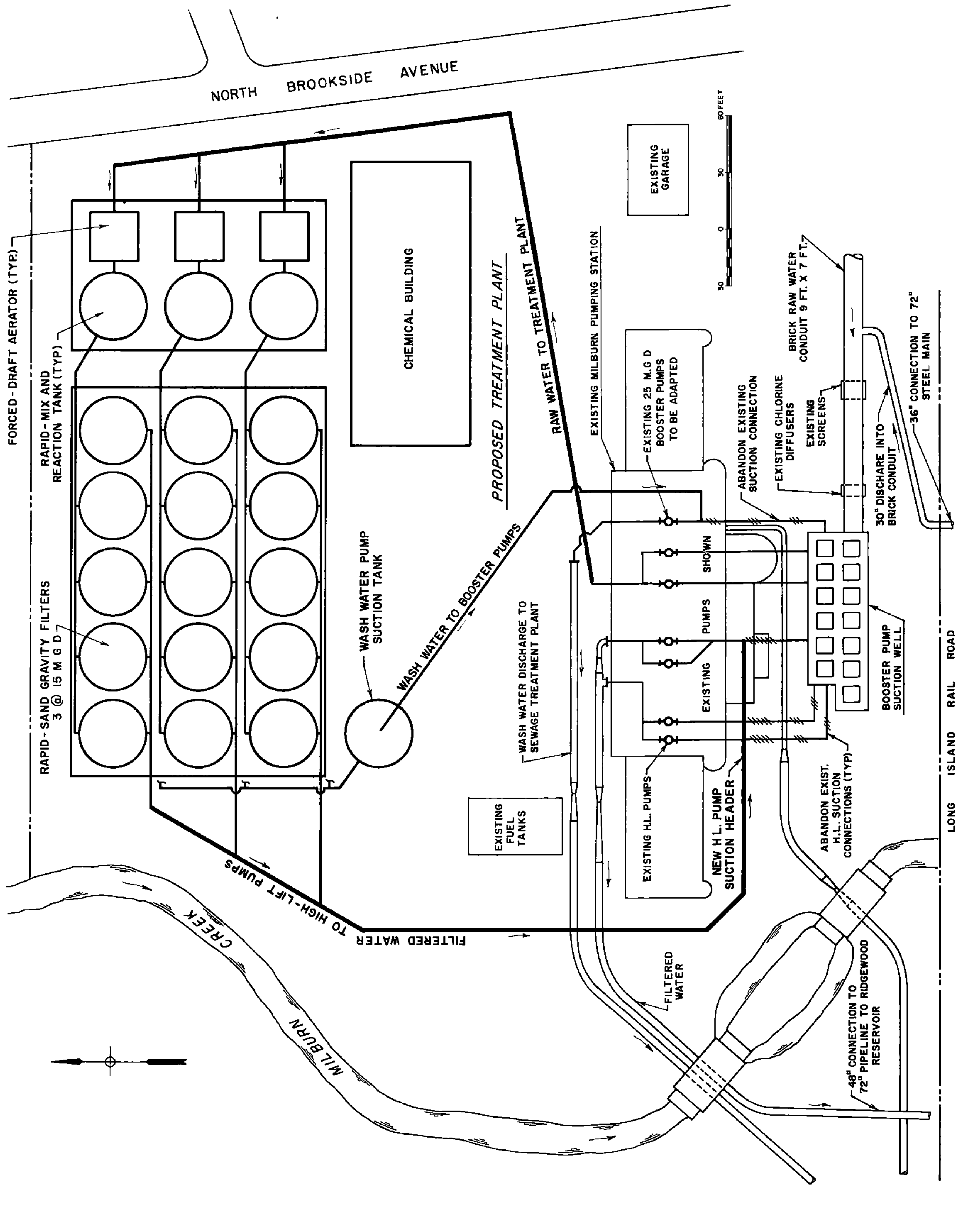

FIG. 15 MILBURN STATION PROPOSED TREATMENT FACILITIES

For the Milburn-Ridgewood project, fixed and operating costs are estimated as follows:

Annual debt service and fixed operating costs	$1,100,000
Variable operating costs for driest year	510,000
Total cost for driest year	$1,610,000
Estimated yield during driest year, million gallons	14,600
Equivalent daily average yield in driest year, million gallons per day	40
Total cost per million gallons	$110

Disposal of Filter Washwater. Iron and manganese bearing sludge and washwater from the treatment plant could not be discharged to nearby watercourses or to the south shore bays because of their offensive color and tendency to stain rocks, boats, and other objects. The waste water can be treated readily with sanitary sewage and may in fact improve operation. It should be discharged to the sanitary sewerage system. The existing brick conduit, or one of the 48-in. cast-iron lines, could be used to facilitate delivery of the waste to the Nassau County Treatment Plant at Bay Park or, if necessary, to the city's Jamaica Bay Treatment Plant west of the John F. Kennedy International Airport. The conduit or 48-in. main would provide considerable storage, more than enough to equalize the intermittent filter washing discharges.

Other Ground Water Areas on Long Island. City-owned wells at Douglaston, Bayside, Whitestone, Flatbush, and other places have been used for water supply in the past. Recent investigations of these sources for the Department of Water Supply, Gas & Electricity have indicated that with proper equipment these wells might deliver a total of 24 mgd. Most of the water is hard, ranging up to 200 or 300 mg/L, the nitrates are high, and the chlorides range from 50 to 700 mg/L in some of the wells. The water is not suitable for domestic purposes without treatment, and continued pumping probably would introduce salt to some of the wells. Their use is not recommended.

Cloud Seeding

In 1950, the City of New York experimented with cloud seeding in an effort to increase rainfall on its watersheds and to relieve the serious water shortage at the time. The cloud seeding was under the direction of W. E. Howell, who has been active commercially in this field since that time. The results have been characterized as successful by some and a failure by others. In any event, some property owners attributed subsequent storm damage to the experiments and filed suit against the city and Howell. The suits apparently have not been pressed.

The value of cloud seeding to increase water supplies in the eastern United States has been questioned seriously, and there has been little enthusiasm in the past 15 years. Interest has been revived, however, in recent months by re-examination of earlier commercial cloud-seeding data and a Final Report of the Panel on Weather Modification and Climate of the National Academy of Sciences and National Research Council, which concludes that despite the statistical inadequacies and certain deficiencies in the operators' records, the results of the operational data "strongly imply that statistically significant increases in precipitation, of the order of 10 percent, can result from seeding." The data cited included fourteen cases of cloud seeding between 1954 and 1964 from New Hampshire to South Carolina in which the apparent increases in rainfall from seeding operations ranged from 0 to 57 percent, with a median of 18 percent.

Conclusions as to the present status and value of cloud seeding have been excerpted from a report prepared for us by F. A. Huff, Research Meteorologist, of the Illinois Water Survey, Urbana, Illinois as follows:

> "1. There is now substantial evidence that cloud seeding will produce small to moderate increases in precipitation from some types of clouds and storm systems. Conservative estimates place the average increase at 10 to 20 percent. The evidence is by no means unanimous and cloud seeding at this time must be classified as a crude, inexact science, Controversy still exists among scientific investigators regarding such questions as seedable types, magnitude of expected increases from seeding, whether natural precipitation may be decreased by overseeding under some conditions, and whether increases produced by seeding in one area may be balanced by decreases in natural precipitation somewhere downstream. The uncertainties apparent in the foregoing statements are the unfortunate but unavoidable result of our inadequate understanding of the basic cloud process which determine the seedability of any given cloud or storm system.

"2. Because cloud seeding is a crude science, an accurate quantitative prediction of the results of any particular seeding program undertaken at this time could not be made and any claims of such capability are not justified. The latest information available to the writer indicates that guarantees are not made by experienced commercial cloud seeding organizations.

"3. Available data indicate that the orographic cloud systems of western United States and cumulus clouds, which are major rain producers in eastern United States during the warmer part of the year, are most likely to produce precipitation increases from seeding operations. There is no clear evidence from United States experiments that the large-scale storm systems (extratropical cyclones), which are the major source of precipitation during the colder part of the year over eastern United States, can be stimulated by seeding, and foreign results are inconclusive.

"4. The strongest evidence for the efficacy of seeding under favorable conditions in eastern United States is the considerable number of apparently successful seeding operations carried out by commercial seeders, the results of which have been supported by independent analyses of the same data by the Panel on Weather Modification and U. S. Weather Bureau scientists.

"5. There is considerable evidence that the experienced commercial cloud seeding organizations have developed operational technology through study and experience which permits them to seed with a higher probability of success than our crude knowledge of basically important cloud processes would indicate.

"6. Examination of data available from cloud seeding operations in eastern United States indicates that the best results are obtained in summer when cumulus clouds are the predominate rain producer.

"7. Cloud seeding is not practical under severe drought conditions. Occasionally, temporary disruptions of drought conditions may occur and the transitional zones around the drought center may contain sufficient clouds and instability to support rainfall. Under these conditions, seeding may produce positive results.

"8. Precipitation increases of the order of 10 to 20 percent from seeding, such as indicated in recent findings of the Panel on Weather Modification, would not normally result in major contributions to surface water supplies during periods of exceptionally dry weather. For example, an increase of 20 percent in the summer 1965 rainfall at LaGuardia Field would have produced a total increase of only 0.90 in., equivalent to an increase of only 7 percent of the normal summer rainfall. A 10 percent increase from seeding would have been equivalent to less than 4 percent of the normal rainfall. A considerably greater contribution would result from successful seeding, if conducted on a routine basis to augment water supplies during near normal or above normal periods of precipitation.

"9. A possible undesirable effect of indiscriminate seeding which cannot be ignored is the increase in soil erosion and sedimentation which could occur through intensification of the rainfall rate in storms that produce natural rainfall of moderate to heavy intensity.

"10. Rapid development in knowledge and operational technology may occur in the next several years as a result of programs planned or under way by the U. S. Weather Bureau, the Bureau of Reclamation and other scientific groups. Disposition of present congressional bills which provide for greater increased funds for research in weather and climate modification will dictate progress in the next several years to a large extent."

We are unable at this time to evaluate fully the potential worth of cloud seeding to New York City and Westchester County. It obviously would provide no important immediate relief. At the same time, the Weather Bureau and other competent agencies should be encouraged to extend their research and experimentations. Only thus will the possibilities be determined.

Sea Water Conversion

The feasibility of sea water conversion in the vicinity of New York City is outlined in "Potentialities and Possibilities of Desalting for Northern New Jersey and New York City" issued by the Northeast Desalting Team in June 1966. This team, consisting of representatives of several federal agencies, relied largely on a feasibility study completed in February 1966 by the Ralph M. Parsons Company for the Atomic Energy Commission and Office of Saline Water. The report indicates that a 300-mgd., 1,500-megawatt, dual-purpose, nuclear plant would cost over $500,000,000 to build, and that the water produced would cost considerably more than that obtained by development of natural sources.

The place of desalting sea water will be explored further in our final report. On the basis of present information, we do not consider desalting an immediate solution to the New York City-Westchester problem.

Comparison of Projects

This analysis has not taken into consideration the comparative quality of water available from several sources, except with respect to the Hudson River and Long Island water resources. In these two cases, water quality is of first importance and the projects proposed include facilities for treatment. Except for the Rondout and Wallkill projects, the upland sources considered would provide soft water, generally low in color, free from excessive turbidity even during periods of flood, and of reasonably good sanitary quality. The Wallkill River drains large areas overlain with peat and muck, and the water frequently carries large quantities of organic matter. Rondout River water is subject to industrial waste pollution above the proposed intake site. The chemical quality of water from creeks east of the Hudson would be comparable to that of Croton Reservoir water. In all instances, the water diverted from streams would pass through reservoirs providing substantial holding time and an opportunity for natural purification. Subject to more detailed studies to follow, we believe these upland sources could be used safely in emergencies with the chlorination and other treatment now proposed.

Costs and yields of the several projects are summarized in Table 3. The projects are not directly comparable in all respects, but the data given are sufficient to indicate in a general way the more preferable solutions.

Additional water from east of the Hudson River obviously would be costly. The capital and operating costs of the Ten Mile River, Fishkill-Wiccopee, Fishkill Creek, and Wappinger Creek projects would be substantially higher than those for other projects. The relatively low cost of Candlewood Lake water is due to the large quantity potentially available, but the figures do not take into account payments to the power company for water taken from Candlewood Lake, presently of unknown magnitude. Perhaps even more important, there is no assurance that the State of Connecticut and potential downstream water users would permit diversion.

West of the Hudson River, the Beaver Kill development is clearly the most attractive. Willowemoc Creek total costs are comparable, but the potential yield is small, making the unit

Table 3. Comparison of Projects

Project	Yield in driest year (comparable to 1965)		Construction cost (000)	Debt service and fixed operating costs, each year (000)	Cost per million gallons in driest year		
	Million gallons	Equivalent average, mgd.			Debt service and fixed operating costs	Variable operating costs	Total
Hudson River Pumping Plant Addition	11,500	32	$ 8,300	$ 762	$ 66	$41	$107
Ten Mile River	6,550	18	22,000	1,465	224	50	274
Fishkill-Wiccopee	7,225	20	22,000	1,420	197	49	246
Fishkill Creek	7,450	20	15,000	979	132	45	177
Wappinger Creek	4,675	13	19,000	1,222	262	66	328
Candlewood Lake	37,000	102	20,000	1,410	38	26*	64*
Rondout Creek	25,600	70	21,000	1,430	56	19	75*
Wallkill River**	33,000	90	21,000	1,445	44	19	63
Beaver Kill	18,250	50	5,000	367	20	12	32
Willowemoc Creek	7,300	20	5,000	367	50	19	69
Long Island ground water	14,600	40	10,000	1,100	75	35	110

* Excluding compensation to power company.
** With booster, construction cost would be $34,000,000 and cost of water $108 per million gallons.

cost of water considerably greater. Obtaining approval of the diversion from the Delaware River Basin Commission is likely to be the most serious obstacle. The Wallkill and Rondout Creek diversions would provide large quantities of water at relatively low cost. The operation and maintenance of large pumping stations, scheduling of pumping, adjustment of flows in the aqueducts, etc., might be difficult and costly to arrange, but certainly are feasible.

Enlarging the Hudson River Pumping Plant by 100 mgd. would increase the daily average yield by only 32 mgd. in a year like 1965, and successful operation would depend upon salt-water intrusion no worse than experienced in the past.

The Long Island ground-water project would not be cheap, but it would provide a source of good water for the John F. Kennedy-Rockaways area. It would feed the city system from the east rather than north and would be invaluable in emergencies. This supply could be used year in and year out, and, if ultimately not needed by the city, could undoubtedly be sold to Nassau County.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Our investigation of the immediate public water supply needs of the City of New York and Westchester County has resulted in the following principal conclusions and recommendations:

Conclusions

1. Water consumption in New York City and Westchester County has averaged approximately 1,300 mgd. over the past five years. Stringent restrictions on water use in 1965 cut the consumption to less than 1,200 mgd.
2. Water service in New York City and Westchester has been maintained during the drought by drawing on Long Island resources, emergency pumping from the Hudson River, and by releasing to the lower Delaware River basin less water than stipulated in the U. S. Supreme Court decree of 1954.
3. New York City and Westchester County may be expected to require an average daily total water supply from all sources on the order of 1,430 million gallons by the year 1975 if present practices are continued.
4. The total daily average water supply requirement for New York City and Westchester County in 1975 could be limited to approximately

1,200 million gallons if conservation practices recommended hereinafter were carried out.

5. Tentative estimates of the safe yield of the New York City and Westchester County water resources indicate that present demands exceed the safe yield of the supply and emphasize the immediate need for conservation measures and additional works to avoid water shortages in the near future.

6. With increasing labor costs and other difficulties in recent years, leak-detection work in New York City has been seriously curtailed.

7. Metering of water in New York City is now limited to industrial, commercial, and a small fraction of the residential services.

8. A number of possibilities exist for increasing the water supply, both from upland and nearby sources. Of the several possibilities considered, only four could be constructed promptly at reasonable cost: enlargement of the Chelsea Pumping Station; enlargement of the Croton system by installing a bypass from the Delaware Aqueduct to the Cross River Reservoir; Beaver Kill floodwater skimming, and flashboards on Cannonsville Dam. These measures combined would not increase

the total yield enough to meet future water needs of New York City and Westchester County.

Recommendations

1. Recognizing that the drought may continue and that construction of a major new water supply will take several years, we recommend that the City of New York seek permission to install flash-boards at Cannonsville and flood-skimming works on the Beaver Kill and proceed promptly with these facilities. The bypass from the Delaware Aqueduct to Cross River Reservoir should be built.
2. We recommend that the city continue its efforts to demonstrate before the Delaware River Basin Commission the urgency of the present situation and the importance of limiting Delaware River releases to the flows actually needed for downstream uses.
3. Meanwhile, New York City should take steps to curtail the use of water, including:
    a. Intensify immediately and prosecute vigorously a continuing leak-detection and elimination program in New York City.
    b. Institute metering of all building services in New York City immediately and program it for completion before 1975.

c. Modernize New York City's procedures for metering, reading and billing and use computer facilities to the fullest extent feasible.

d. Pending completion of the recommended metering, inspect premises in New York City served by unmetered water services at least once every five years for leakage and violations of the Department of Water Supply, Gas & Electricity regulations.

e. Revise water rates in New York City so that a metered supply becomes more attractive financially than an unmetered supply.

f. Pending completion of these steps, apply general restrictions of water use as necessary and when warranted by inadequate water reserves.

ACKNOWLEDGMENTS

We acknowledge with appreciation the cooperation and assistance of federal, state, municipal and private agencies in providing information essential for the study covered by this report.

Respectfully submitted,

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APPENDIX A

WATER CONSUMPTION DATA

Table A-1. Water Supplied from Ground-Water Sources in Westchester County, 1960-1964

Community	Millions of gallons				
	1960	1961	1962	1963	1964
Amawalk-Shenorock	21.75	23.75	22.59	22.25	21.64
Bear Ridge Lake Corp.	7.00	9.00	4.50	5.60	10.10
Bedford-Katonah	116.20	130.92	137.10	78.49	76.81
Bedford Farms Co.	5.13	5.30	5.58	5.58	6.00
Bloomerside	2.80	2.80	2.80	3.00	3.00
Briarcliff Manor	182.27	190.62	181.79	133.67	114.41
Butlerville	1.75	0.75	0.73	0.73	0.73
Candlewood Park	-	1.57	1.60	1.60	1.60
Croton Falls	3.29	5.00	5.00	3.00	3.00
Croton on Hudson	408.16	348.08	362.15	343.59	272.34
Goldens Bridge Colony	4.32	4.32	4.32	4.50	4.50
Harrison W.D. #1	0.05	0.86	14.80	5.50	5.19
Lake Katonah	2.85	3.41	3.41	3.39	3.72
Lake Kitchewan	2.10	2.10	-	-	-
Meadowbrook W.D.	0.97	2.56	2.56	2.56	6.43
Mastri-(Underhill Hts.)	1.06	1.06	1.06	1.06	1.06
Mount Kisco	44.58	44.82	73.00	-	66.11
North Castle	68.74	60.48	66.80	68.40	82.28
Northam Westchester C.C.	2.19	2.23	2.23	2.30	2.31
Pleasantville	125.57	123.94	121.09	96.31	96.33
Thornwood	77.13	83.92	86.85	84.26	88.61
Truesdale Corp.	4.65	5.00	5.40	8.41	7.87
Twin Lakes	0.60	0.65	3.50	3.50	3.50
Usonia Homes (Mt. Pleas.)	4.83	4.10	4.00	4.00	5.50
Vail's Grove	5.00	1.70	5.00	1.70	2.70
White Plains	83.20	42.64	67.84	52.04	59.21
Windmill Farms	23.00	26.56	32.39	32.92	35.60
Yonkers	176.12	163.15	142.87	97.67	55.92
Yorktown	104.68	141.82	100.55	121.18	65.44
Cortlandt-Mohegan	21.69	-	-	-	-
Crompond	12.75	-	-	-	-
Lewisboro-(Meade Prop.)	-	-	3.50	-	-
Total	1,514.43	1,433.11	1,465.01	1,187.21	1,101.91
Equivalent mgd.	4.2	3.9	4.0	3.2	3.0

Table A-2. Water Supplied from Surface Sources in Westchester County, 1960-1964

Community	Millions of gallons 1960	1961	1962	1963	1964
Greenburgh (incl. Greenville & E. Irvington)		6.86	-	-	10.53
Irvington	69.21	-	30.19	-	-
Larchmont	282.44	294.83	297.64	292.22	296.04
Lewisboro (Meade Prop.)	5.00	5.00	-	0.90	0.90
Montrose W.D.	0.32	-	-	17.94	-
Mount Kisco	192.59	238.78	193.15	278.28	263.12
New Rochelle Wat. Co., New Rochelle Div.	-	-	-	-	12.48
Pocantico Div.	1,165.70	1,126.30	1,091.55	1,036.99	875.03
Ossining Vg. & Town	362.81	345.00	344.10	295.20	235.00
Peekskill	1,754.40	1,798.81	1,859.33	1,871.51	1,730.72
Roe Park W. D.	82.87	83.52	98.31	117.94	-
Pocantico Hills	38.70	29.97	34.62	52.04	53.81
Port Chester Wat. Co.*	1,777.17	1,838.93	1,843.95	2,000.00	2,124.30
Scarsdale	20.09	-	567.45	-	-
Tarrytown	511.00	542.14	517.13	299.00	315.51
Westchester Jt. W. W.	619.29	753.55	365.77	314.24	453.25
White Plains	247.60	118.73	262.21	240.82	196.42
Yonkers	3,604.17	2,963.77	2,684.71	1,536.98	2,666.35
North Tarrytown	-	6.00	-	-	-
New Castle W.C.	-	-	30.15	22.70	-
Old Farm Hill W.D.	-	-	-	9.30	-
Total	10,933.36	10,152.19	10,220.26	8,386.06	9,233.46
Equivalent mgd.	29.4	27.9	28.0	23.0	25.3

* Connecticut sources

Table A-3. Per Capita Nonindustrial and Noncommercial Use and Unaccounted-for Water in 25 U. S. Cities of Over 500,000 Population

City or Utility	Per capita quantity, gpd.
Philadelphia Suburban Water Company	60.3
Indianapolis Water Company	60.3
Atlanta	63.6
Jamaica Water Supply Company (New York City)	64.2
Louisville	66.0
St. Louis County Water Company	66.4
Kansas City	70.0
San Francisco	73.8
Dallas	75.0
Columbus	76.2
Newark	76.2
Milwaukee	76.5
Cincinnati	80.7
Memphis	81.0
RICHMOND	84.0*
Detroit	100.0
QUEENS	101.0*
Pittsburgh	105.0
East Bay Municipal Utility District (California)	107.0
BROOKLYN	107.0*
San Diego	108.0
NEW YORK CITY	116.0*
Miami	119.0
Los Angeles	121.0
Baltimore	121.0
MANHATTAN AND BRONX	131.0
Washington	144.0
Buffalo	149.0
Denver	204.0

* Average 1954 to 1964

APPENDIX B

CONSTRUCTION COST ESTIMATES

Table B-1. Estimated Construction Cost of Additional 100-mgd. Hudson River Pumping Plant at Chelsea

Item	Estimated cost*
1. Intake	$1,000,000
2. High-lift pumping station - 100 mgd.	4,000,000
3. Chemical feed facilities - alum and chlorine	110,000
4. Force main	400,000
5. Shaft and tunnel	1,100,000
6. Tunnel connection	300,000
Subtotal	$6,910,000
7. Engineering and contingencies	1,390,000
Total	$8,300,000

*Consultants engaged by the Board of Water Supply to study the feasibility of increasing the capacity of the existing plant have furnished preliminary information concerning a plan that would use the existing shaft and have a smaller construction cost.

Table B-2. Estimated Construction Cost of Ten Mile River Project

Item	Estimated cost
1. Diversion structure	$ 60,000
2. Pumping stations	
Ten Mile River - 300 mgd.	6,900,000
Low to high level	1,990,000
3. Transmission mains	
43,500 ft. - 84 in. diameter	9,200,000
1,100 ft. - 66 in. diameter	150,000
Subtotal	$18,300,000
4. Engineering and contingencies	3,700,000
Total	$22,000,000

Table B-3. Estimated Construction Cost of Fishkill Creek - Wiccopee Creek Project

Item	Estimated cost
1. Diversion structure	$ 90,000
2. Pumping station - 200 mgd.	9,200,000
3. Transmission main	
24,700 ft. - 84 in. diameter	6,310,000
4. Tunnel	
5,600 ft.	2,800,000
Subtotal	$18,400,000
5. Engineering and contingencies	3,600,000
Total	$22,000,000

Table B-4. Estimated Construction Cost of Fishkill Creek - Fishkill Project

Item	Estimated cost
1. Diversion structure	$ 80,000
2. Pumping station - 200 mgd.	7,200,000
3. Transmission main	
21,000 ft. - 72 in. diameter	3,600,000
4. Shaft No. 6 connection	1,400,000
5. Chemical treatment facilities	220,000
Subtotal	$12,500,000
6. Engineering and contingencies	2,500,000
Total	$15,000,000

Table B-5. Estimated Construction Cost of Wappinger Creek Project

Item	Estimated cost
1. Pumping station - 200 mgd.	$ 9,200,000
2. Transmission main	
25,300 ft. - 72 in. diameter	5,000,000
3. Shaft No. 6 connection	1,400,000
4. Chemical treatment facilities	220,000
Subtotal	$15,820,000
5. Engineering and contingencies	3,180,000
Total	$19,000,000

Table B-6. Estimated Construction Cost of Candlewood Lake Project

Item	Estimated cost
1. Pumping stations	
Candlewood Lake - 250 mgd.	$ 3,800,000
Low to high level - 250 mgd.	3,800,000
2. Transmission main	
36,100 ft. - 84 in. diameter	7,100,000
3. Tunnel	
3,500 ft.	1,760,000
4. Channel improvements	60,000
5. Chlorination facilities	180,000
Subtotal	$16,700,000
6. Engineering and contingencies	3,300,000
Total	$20,000,000

Table B-7. Estimated Construction Cost of Rondout Creek Project

Item	Estimated cost
1. Dam and pipes to settling basins	$ 400,000
2. Settling basins	1,300,000
3. Pumping station - 500 mgd.	13,000,000
4. Force main	2,600,000
5. Connection at Catskill Aqueduct	200,000
Subtotal	$17,500,000
6. Engineering and contingencies	3,500,000
Total	$21,000,000

Table B-8. Estimated Construction Cost of
Wallkill River Project

Item	Estimated cost
1. Dam and pipes to settling basins	$ 500,000
2. Settling basins	1,300,000
3. Pumping station - 500 mgd.	13,000,000
4. Force main	2,600,000
5. Connection to Catskill Aqueduct	100,000
Subtotal	$17,500,000
6. Engineering and contingencies	3,500,000
Total	$21,000,000

Table B-9. Estimated Construction Cost of
Facilities to Provide a Connection Between the
Catskill and Delaware Aqueducts Via a Booster Station

Item	Estimated cost
1. Booster station - 500 mgd.	$10,700,000
2. Connection at Delaware Aqueduct	100,000
Subtotal	$10,800,000
3. Engineering and contingencies	2,200,000
Total	$13,000,000

Table B-10. Estimated Construction Cost of Beaver Kill Project

Item	Estimated cost
1. Earthwork	$2,000,000
2. Intake shaft and tunnel	1,000,000
3. Concrete masonry	500,000
4. Control gates and accessories	300,000
5. Chlorination building and equipment	300,000
6. Site work	100,000
Subtotal	$4,200,000
7. Engineering and contingencies	800,000
Total	$5,000,000

Table B-11. Estimated Construction Cost of Willowemoc Creek Project

Item		Estimated cost
1. Earthwork		$1,000,000
2. Intake shaft and tunnel		
750 ft. shaft	$ 750,000	
2,000 ft. tunnel	1,600,000	
		2,350,000
3. Concrete masonry		300,000
4. Control gates and accessories		200,000
5. Chlorination building and equipment		200,000
6. Site work		100,000
Subtotal		$4,150,000
7. Engineering and contingencies		850,000
Total		$5,000,000

Table B-12. Estimated Construction Cost of Long Island Ground-Water Project

Item	Estimated cost
1. Rehabilitation and improvements to ground-water supply sources	$ 1,000,000
2. Milburn water treatment plant addition and booster pumping station alterations	6,000,000
3. Filter wash-water disposal facilities	500,000
4. Rehabilitation of 72-in. transmission line (subject to inspection and testing)	500,000
Subtotal	$ 8,000,000
5. Engineering and contingencies	2,000,000
Total	$10,000,000

APPENDIX C

WATER ANALYSES

Table C-1. Water Analyses for Long Island Surface Supplies

Pond	Years	Coliforms - M.P.N. (per 100 ml.) Median	20% of values= or exceed	10% of values= or exceed
Massapequa	1946-50	38	240	2,400
	1951-53	38	240	2,400
	1957-58	240	2,400	24,000
	1963-66	2,400	240,000	2,400,000
Wantagh	1946-50	38	240	240
	1951-54	38	240	2,400
	1957-58	38	2,400	24,000
	1963-66	240	24,000	240,000
East Meadow	1946-50	38	240	240
	1952-54	240	240	2,400
	1957-58	2,400	24,000	24,000
	1963-66	2,400	24,000	240,000

Table C-2. Water Analyses for Long Island Ground-Water Supplies

	Year	Massapequa Gallery		Wantagh Gallery		Massapequa Wells		Wantagh Wells		Agawam Wells	
		Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Turbidity,	1965	9.85	80.0	7.5	140.0	2.7	3.0	1.6	3.0	1.8	7.0
s.u.	1966	2.3	4.0	2.1	4.0	2.7	11.0	1.4	2.0	1.5	3.0
Color,	1965	14.75	60.0	12.95	50.0	16.0	23.0	12.6	70.0	4.8	18.0
s.u.	1966	5.85	13.0	6.7	17.0	17.3	30.0	9.5	13.0	3.8	5.0
Iron,	1965	2.45	11.0	2.22	42.0	1.29	2.5	0.73	2.6	0.3	0.49
mg/L as Fe	1966	0.198	0.26	0.20	0.32	0.83	1.24	0.57	0.78	0.28	0.39
Mn,	1965	1.28	1.8	1.25	2.0	0.217	0.5	0.084	0.10	0.373	1.00
mg/L as Mn	1966	1.169	1.28	0.99	1.40	0.149	0.20	0.059	0.12	0.184	0.20
ABS,	1965	1.34	1.8	1.18	2.2	0.0	0.0	0.0	0.0	0.12	0.3
mg/L as ABS	1966	1.12	1.7	1.03	1.2	0.36	0.4	0.03	0.1	0.07	0.1
Coliforms,	1965	0.0*	2.2	0.0	5.1	0.0	0.0	0.0	0.0	0.0	2.2
MPN/100 ml.	1966	0.0*	16.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0

* Median values